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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Crew Size Sensitivity Study of a Multi-Disciplinary Earth Orbital Space Station

TM-69-1015-6

DATE-September 19, 1969

FILING CASE NO(S)-720

AUTHOR(S)- S. L. Penn

FILING SUBJECT(S)-Crew Size
(ASSIGNED BY AUTHOR(S)- Manned Space Station
Mission Planning

ABSTRACT

The relationships between crew size and operational and experimental performance are investigated. Crews consisting of one man to seven and more are analyzed in order to determine their capabilities compared with those of a six-man crew on a Reference Mission. A simple parametric analysis does not prove feasible. The current uncertainties regarding space stations, work loads, and degrees of automation preclude confident selection of optimum crew sizes, but trends and significant factors are pointed out, including the following:

- On the Reference Mission, medical activities (4.5 hours per man) take almost half the available work time. A reduction of medical testing would allow more support of other scientific, applications, and technology (SA&T) activity, a benefit of significance to crews of all sizes, but particularly to small ones. On the other hand, retention of extensive medical testing for small crews might compensate for their reduced statistics in qualifying man for long duration flights. However, a reduction of each man's daily medical program from 4.5 to four hours is advocated for all crew sizes, since it considerably increases the flexibility in mission scheduling.

- Personal maintenance time is set at 14 hours for all crew sizes. While there is some built-in flexibility,

(NASA-CR-112625) CREW SIZE SENSITIVITY STUDY OF A MULTIDISCIPLINARY EARTH ORBITAL SPACE STATION (Bellcomm, Inc.) 53 p

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ABSTRACT (Continued)

small crews are more likely to use the time as intended, since their need for respite from work tasks is expected to be greater than that of larger crews.

• Real time use of a computer in activity scheduling is possible, but will probably depend, and cannot necessarily count, on the cooperation of the crew in apprising the computer of their own status and that of the experiments.

• Under certain circumstances small two- or three-man crews, or even a single man, could conduct useful multi-disciplinary missions. While small crews would have difficulty in meeting gross accomplishment objectives and in performing two-man and round-the-clock activities, large crews (much above six) would suffer some loss in average work output per man, due largely to organizational factors.

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SUBJECT: Crew Size Sensitivity Study of a Multi-Disciplinary Earth Orbital Space Station
Case 720

DATE: September 19, 1969

FROM: S. L. Penn

TM-69-1015-6

TECHNICAL MEMORANDUM

I. Introduction

A. Statement of Problem

A six-man multi-disciplinary earth orbital space station mission was defined and analyzed within Bellcomm during the latter part of 1968[1,2] and is referred to hereafter as the Reference Mission. The adopted crew size and program for that mission were derived respectively from an instinctive preference for six men and a process of iterative engineering judgments, with both benefitting from familiarity with previous space station studies. In order to more critically assess those determinations and to enable increased skill in making such selections for future space station models, this tradeoff study between crew size and mission performance has been conducted. The Reference Mission is the principal point of departure and comparison. Pertinent aspects of that Mission are reviewed in Section II.

The tradeoff questions include the following:

--How much would the mission suffer or gain as crews of different size attempted to meet essentially the same work objectives in equal periods of time (the mission duration)? A corollary to this is:

--How would the accomplishments of different crew sizes relate to the nature of the work tasks and to the ground rules or assumptions?

More specific aspects of these are:

--Keeping the work tasks fixed, how will output vary with crew size?

--Which tasks or procedures must change, and how, to enable attainment of the same goals by smaller crews? How little can you change the tasks to suffer minimum degradation in meeting objectives and still make do with smaller crews?

--How would the character of the mission change as crews got smaller?

--For any given crew size, how sensitive is the work output to time spent in personal maintenance (e.g., six hours sleep instead of eight), to the pace at which work is done (e.g., three-shift day instead of one or two), to the operational requirements of the experiments (e.g., two-man versus one-man operation; fixed versus flexible durations), etc.?

B. Approach

Two approaches to the study of crew size sensitivity were successively taken, the second because the first failed. The first is worthy of note because it was the instinctive, systems analysis approach, which, in this case, did not lend itself to handling the real life problem.

Briefly, the first approach was to do a parametric study of the crew sensitivity problem. First, the factors that might influence crew size would be identified. Then, they would be varied one at a time, and their relationship to crew size examined in matrix form. Table I is a list of these factors.

Table I - Crew Size Factors

1. Operations Philosophy - e.g., automated vs. manned watch.
2. Maintenance Philosophy - Degrees of reliability and redundancy determine repair activity required.
3. Round-the-Clock Experiment Support - Requirement for man awake at all times affects level of manpower available for work.
4. Qualification of Man for Extended Flight - Pace at which we qualify man for extended flight is a function of how many men have to be checked for acceptable statistics.
5. Biomedical Test Philosophy - Related to 4 above. Typically, concerns the amount of two-man medical activity required and duration of medical tests.
6. Degree of Experiment Automation - Most experiments are subject to individual tradeoff studies, but general policy may also be adopted.
7. Psychological Considerations
8. EVA Capability Desired - e.g., two-man-out capability may require two more for support. Depends on philosophy.

9. Need for Backup Man - What contingency capability is desired? Do we meet contingencies by having an unoccupied man available, or do we stop an ongoing activity?
10. Length of Work Day - 8 hour? 10 hour? 12 hour? Certainly affects crew size required for a given work load.
11. Size, Variety, and Mutual Compatibility of Experiment Payload
12. Logistics Resupply Interval - Includes potential for crew exchange.
13. Role of Man - Relates strongly to 1 and 2 above. Size (and makeup) of crew depends on whether man's role is, typically:

    a) Repairman (keeping things fixed and in working order);
    b) Operator (with little repair duty);
    c) Monitor (with little operation and repair);
    d) Scientist (changing experiment design, writing new programs for computer, etc.); or
    e) Combination of some or all of above.

The above factors proved to be too interrelated and complex for a simple matrix analysis. A qualitative attempt to describe anticipated effects of parameter manipulations on crew performance and output also failed. Instinctive judgments as to the results of these manipulations often did not lead to mutually compatible events, capable of being scheduled in actual time lines. In short, a more limited, pragmatic approach was required.

The second and adopted approach to this study of crew size sensitivity is as follows:

First, the six-man Reference Mission, accompanied by figures depicting a nominal day on that mission, pertinent data describing different levels of activity, and a man by man schedule, is reviewed. The schedule is then revised to reflect a four hour per day level of medical activity instead of the original 4.5 hours. This expedites comparison with other crew size schedules, which had proved simpler to prepare on the four-hour basis. Then, beginning with a crew of only one man, crews of increasing size are analyzed to see what they could accomplish, and their outputs are compared with that of the Reference Mission. The effects of various restrictions and assumptions are noted. As few modifications as practical are made. The selection of modifications and operating modes is on a pragmatic, engineering judgment basis, leaving some possibilities unstudied, but presenting one or more realistic alternatives at each crew size as representative of the changing capabilities and requirements. Lastly, a comparison of a six-man and a three-man crew on a considerably shortened medical schedule, more in consonance with some later thinking(3), is presented. All these treatments pay particular attention to the effects of crew size on the performance of science, applications, and technology (SA&T) experiments and on the qualification of man for extended operations in space.

To reasonably limit our study we adopt certain of the ground rules from the Reference Mission. These amount to keeping some of the factors from Table I constant, namely:

From 2. - Safety critical features shall be redundant.

From 8. - There shall be no requirement for operational EVA. This allows us to consider crew sizes of less than four men.

From 11. - The mission shall be multi-disciplinary.

From 12. - A 90 day logistics cycle is assumed.

Also, we do not consider the impact of crew size on habitability, life support, or logistics requirements. Furthermore, we assume that assigned tasks are capable of performance within their allotted times. Should it be learned after a mission has begun that this is not the case, less work would be accomplished than planned; that is, there would be fewer completed tasks. But if we learn earlier, e.g., from AAP, that work capability in space is restrictively limited (e.g., preparations for LM entry in Apollo 8 took longer than expected), then we would either plan to provide larger crews for the required work load or prepare to rely even more heavily on automation.

II. Review of the Six-Man Reference Mission

Reference 2, which describes the Reference Mission, presents a typical day on a multi-disciplinary, earth orbiting space station. On that mission a crew of six follows a three-shift day with two men asleep and four awake at all times. Operations are largely automated. The productive activity consists of the performance of experiments, principally in astronomy, earth applications, biomedicine, and bioscience.

The referenced study suggests that, on the average, with a six-man crew, one man should be kept free of "connected type" tasks (characterized by continuity or by regular and frequent performance --likely to be degraded by interruptions). This would generally allow spot assignment, with minimum impact on ongoing, regular activities, to meet the numerous unscheduled, additional work loads that can occur. A mission sequence plan for a nominal day was presented, and is shown again here in Figure 1. The plan includes a sizeable complement of preprogrammed experiments and a variety of planned, short duration tasks, while providing sufficient flexibility to permit the performance of a reasonable number of anticipated contingency and emergency tasks.

Figure 2 summarizes the activity data from Figure 1. The man hours spent in operational, SA&T, medical, and swing-time activities are shown for each of three different types of day (discussed in the Appendix), summed, and compared with the man hours available for work (10 hours per man per day). Applicable definitions and ground rules are included with the Figure. The Minimum Day is seen to require an average of almost 7 5/6 hours per man, or 78% of the available time. 45% of the available time (and a majority or the actual working time) is spent in medical activities. In the Busy Day, swing-time activities are included only when at least 1½ uninterrupted hours (about 1 orbit) are available for their performance. This raises the average work time to 9 1/3 hours, with medical activities taking slightly less than half. The Hectic Day portrays an arbitrary but representative situation in which flares are occurring during a period when the sun is active and increased manpower is required for the associated solar observations. The stepped-up level of activity still doesn't exceed available manpower on an average basis, but does require some juggling of the nominal schedule, as indicated in the chart notes. With the stepped-up level of SA&T as indicated, there are no longer any available free periods of 1½ hours or more in duration, so swing-time tasks are not performed. Still, there is about an hour per man of free time.

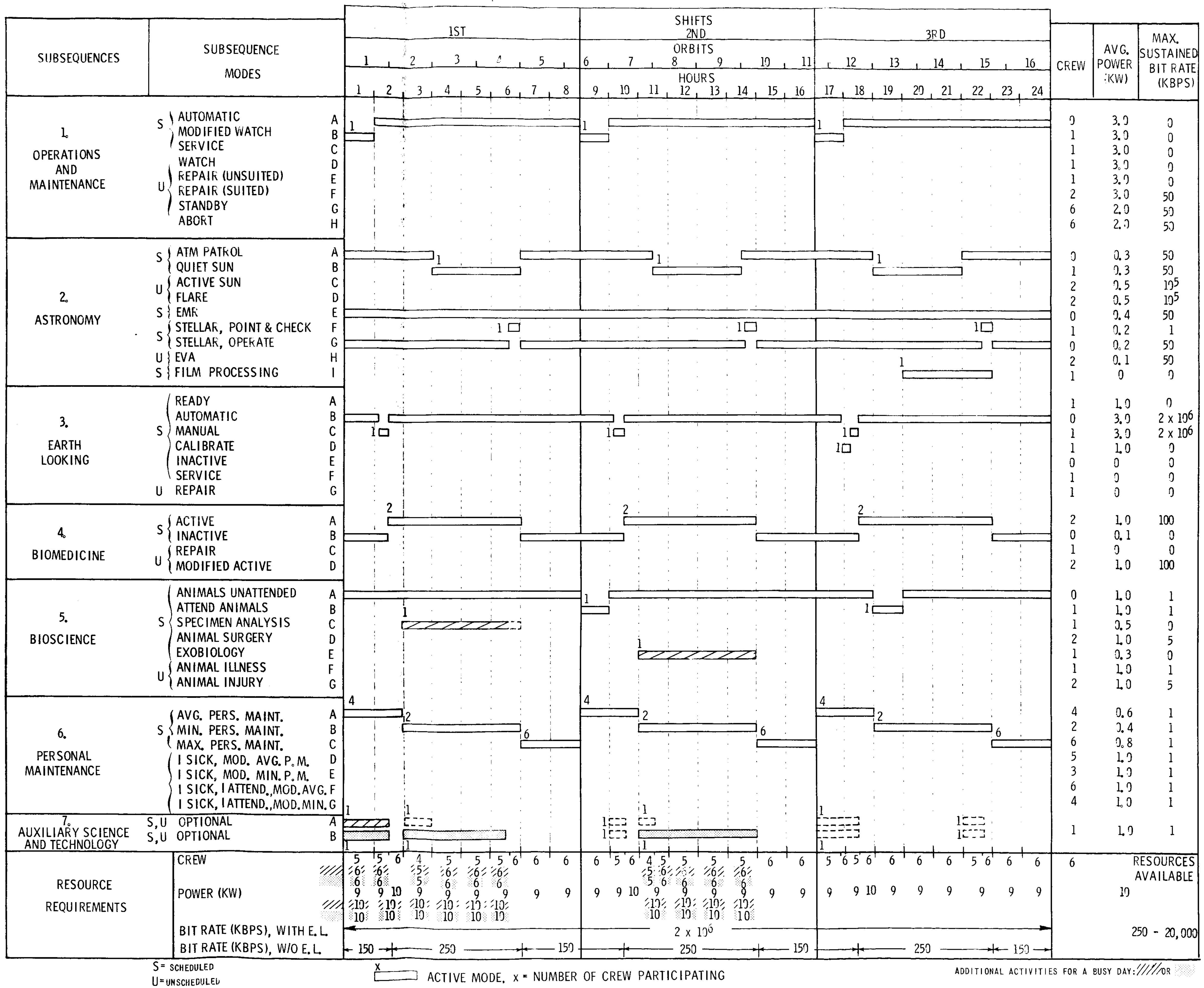


FIGURE 1 - MISSION SEQUENCE PLAN FOR A MULTIDISCIPLINARY SPACE STATION - A NOMINAL DAY

FIGURE 2 - TASK ASSIGNMENT SUMMARY FOR 6-MAN M-D MISSION (NO. OF MEN OCCUPIED)

ACTIVITY		← 1st Shift, 8 hrs →								2nd Shift, 8 hrs →								3rd Shift, 8 hrs →								Man Hours	% of total
LEVEL	TYPE*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Assig.	avail.
MINIMUM (Nominal)	O & M	1								1								1								3	5
	SA&T		1		1	1	1|2			1	1	1	1	1	1				1	2	2	2	1|2			17	28
	MEDICAL		2	2	2	2	2				2	2	2	2	2				2	2	2	2	2			27	45
	Sw. Tm.																										
	TOTAL	1	1|2	2	3	3	3|4	0	0	2	1|2	2|3	3	3	3	0	0	1	1|2	4	4	4	3|4	0	0	47 (of 60)	78
																					Avg. per man					7 5/6	78
																					Unassigned					2 1/6	22
																					TOTAL					10	100
BUSY (Nominal	O & M	1								1								1								3	5
	SA&T		1		1	1	1|2			1	1	1	1	1	1				1	2	2	2	1|2			17	28
	MEDICAL		2	2	2	2	2				2	2	2	2	2				2	2	2	2	2			27	45
	Sw.Tm.	1	1	1	1	1	1					1	1	1	1											9	15
	TOTAL	2	2	3	4	4	4	0	0	2	1|2	3|4	4	4	4	0	0	1	1|2	4	4	4	3|4	0	0	56 (of 60)	93
																					Avg. per man					9 1/3	93
																					Unassigned					2/3	7
																					TOTAL					10	100
HECTIC** (Off-Nom.)	O & M	1								1								1								3	5
	SA&T	1	1	1	2	2	2			1	1	2	2	2	2|1			1	1	2	2	2	1|2			25	42
	MEDICAL		2	2	2	2	2				2	2	2	2	2				2	2	2	2	2			27	45
	Sw. Tm.																										
	TOTAL	2	1|2	2|3	4	4	4	0	0	2	1|2	2|4	4	4	4|3	0	0	2	1|2	4	4	4	3|4	0	0	55 (of 60)	92
																					Avg. per man					9 1/6	92
																					Unassigned					5/6	8
																					TOTAL					10	100
No. of men available		2	2	4	4	4	4	0	0	2	2	4	4	4	4	0	0	2	2	4	4	4	4	0	0		

FIG. 2

LEGEND

*O & M (Operations & Maintenance) covers work activities not directly involved with the conduct of scientific or medical experiments. Includes support activities, such as modified watch, repair (not shown here), etc. Excludes calibration, pointing, etc.

SA&T, on this chart, means regular, daily scientific, applications, and technological activities.

Sw. Tm. (Swing Time) means other, infrequent (though possibly scheduled) SA&T.

MEDICAL covers subject, observer, and laboratory technician time.

**Includes unscheduable though not necessarily undesirable events. For this example we use active sun and two flares/day, one during patrol mode (automated, 1st HR) and other during active sun (and replacing it for one orbit; e.g., 12th HR). These necessitate some acceptable schedule shifts, as explained in Reference 2.

Some Ground Rules:

1. 24 HR DAY. 6 Day work week, 7th Day off.
2. 14 HR/DAY personal maintenance (Sleep, eat, exercise, etc.)
3. Up to two flares (but no more, perhaps, than 1/shift) may be studied in any one day, so long as they're not in maximum P. M. mode (unless $\geq$ importance 2).
4. To retain capability for Hectic Day, normal schedule must be either Minimum or Busy Day (Latter having suspendible swing time activities).

It is important to note that if only 8 hours per day had been allowed for work there would have been no time for technical activities other than those which are preprogrammed and connected. There would also have been no capability for conducting extended 2-man activities (other than medical), such as active sun astronomy or animal surgery, unless other duties were suspended. The probability of an 8-hour limit, while considered low, will depend on the intensity and variety of work in space. If the tasks are of sufficient variety and don't prove unexpectedly exhausting, the assignment of more than 8 hours work would not be unreasonable. At the other extreme, if we considered extending each man's work day to 12 hours, we could accommodate swing time activities as well as the activities of a Hectic Day and still have a little additional flexibility for handling contingency events. It is estimated that unassigned time would then amount to about 1½ hours per man, showing that he needn't work the whole 12 hours even though he is available.

To complete the picture for the Reference Mission (on the principal, 10-hour-availability basis), and to facilitate comparison with other crew sizes, a breakdown of individual crewman assignments is shown in Figure 3 and its accompanying data summary. The formats are explained further in the Appendix.

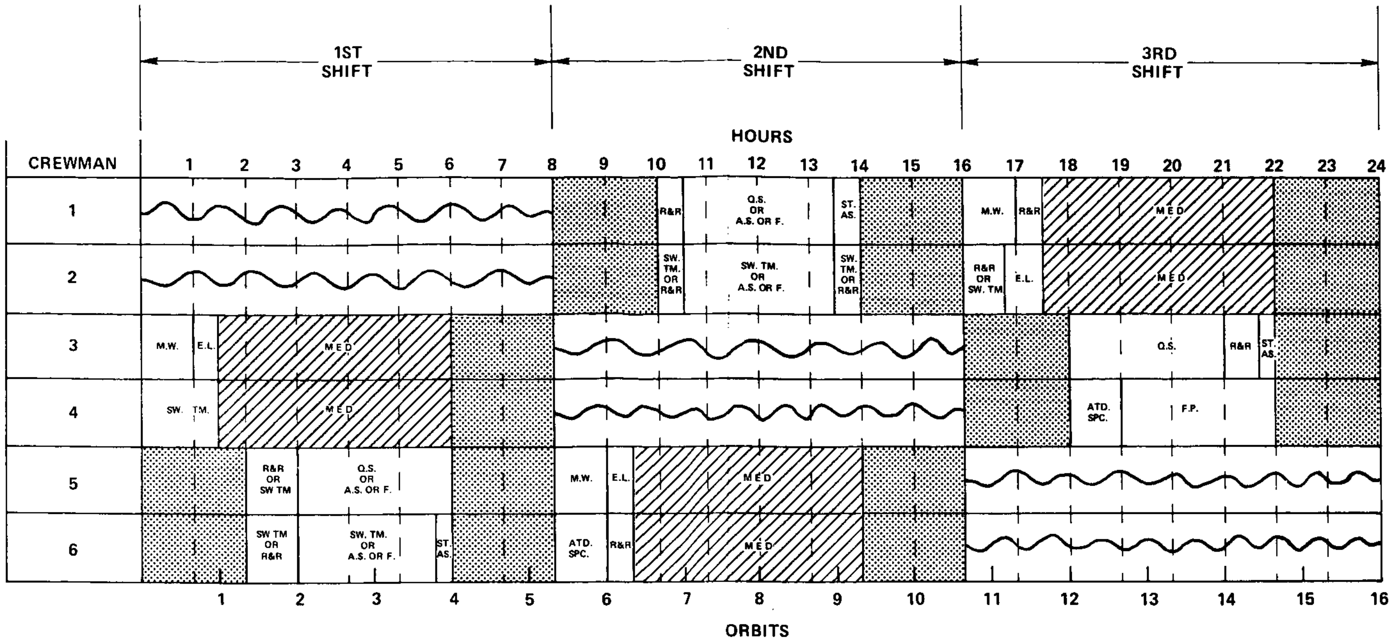
III. Factors of Broad Applicability

Some factors having broad applicability to crew size considerations and, therefore, deserving separate treatment are: the medical program, personal maintenance, solar astronomy (as an example of a major, highly demanding SA&T activity), onboard computers, and the length of the work day.

A. Role of the Medical Program

A major purpose of the onboard medical program is to help qualify man for extended space flight. The tests conducted will provide assurance as to the crew's current and future well being. Space Medicine (NASA/MM) thinking at the time of the Reference Mission study was that there should be one medical experimentation period of 4.5 hours per day for each two astronauts. This is the time required each day for two men to cooperatively meet their combined medical requirements

FIGURE 3 - CREW INFLIGHT SCHEDULE - 6 MEN
(4.5 HR MED PROGRAM)



LEGEND

SLEEP

PERSONAL MAINTENANCE (EAT, EXERCISE, HYGIENE, HOUSEKEEP)

MEDICAL EXPERIMENTS
S = SUBJECT
O = OBSERVER
L.T. = LABORATORY TECHNICIAN

WORK AVAILABILITY
A.S. OR F. = ACTIVE SUN OR FLARES
Q.S. = QUIET SUN
SOL. AS. = SOLAR ASTRONOMY
ST. AS. = STELLAR ASTRONOMY
E.L. = EARTH LOOKING
F.P. = FILM PROCESSING
M.W. = MODIFIED WATCH
ATD. SPC. = ATTEND SPECIMENS
BIO. = BIOSCIENCE
SW. TM. = SWING TIME
R&R = REST & RECREATION

FIG. 3

DATA SUMMARY FOR FIGURE 3 (HOURS PER ACTIVITY)
6-MAN CREW (4½ HR. MED. PROG.)

CREWMAN	ACTIVITY										TOTAL		
	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	MIN. DAY	BUSY DAY	R&R
1	1	4½	3		½	-	-	-		-	9	9	1
2	-	4½	-		-	½	-	-		4	5	9	1
3	1	4½	3		½	½	-	-		-	9½	9½	½
4	-	4½	-		-	-	3	1		1½	8½	10	-
5	1	4½	3		-	½	-	-		-	9	9	1
6	-	4½	-		½	-	-	1		3½	6	9½	½
TOTAL	3	27	9		1½	1½	3	2		9	47	56	4
										MED.	-27	-27	
										SA&T (+D.A.)	20	29	

COMMENTS ON SCHEDULE AND DATA SUMMARY

E.L. Should be rescheduled where incompatible with ephemeris. C.M. #3 can split M.W. and do E.L. at end of 1st hr., instead of in dark as shown. C.M. #5 should reverse assigned order of M.W. and E.L. in 9th and 10th hrs.

To perform ST. AS. in dark on 3rd shift, C.M. #3 should reverse R&R and ST. AS. in 22nd hr.

Support of active sun observations during 3rd shift requires tricky juggling of ATD. SPC. and as subject, observer, and laboratory technician. The impact of such a heavy medical program on the output of a multi-disciplinary mission is severe, especially as the crew size diminishes from six, as will be shown later.

The motivation for reducing crew health medical testing is to provide more time for technically oriented SA&T, either medically related, such as biotechnology, human engineering, and EVA, or nonmedical. Even the small reduction from 4.5 to 4 hours, assumed feasible in this study, substantially increases scheduling flexibility.

Toward the end of the reference study, it was believed within Bellcomm[3] that the medical time requirement could be reduced without serious impact to 1 3/4 hours as a subject and 3/4 hours as an observer for each man, with one of every two men requiring an additional 0.8 hours as a technician. Hence, the total time for one man would be 2½ hours per day and for his partner 3.3 hours per day. The whole medical period would only last 3.3 hours, since the men would begin their activities simultaneously. The effects of implementing that short a program for 6-man and 3-man crews are explored later.

While we would like to reduce the duration of the medical activities as just suggested, we realize that these activities assume increasing importance as crews get smaller, since the statistical return is also getting smaller. Hence, it may pay to keep medical testing at 4 hours for small crews and to reduce it to the 2.5-3.3 hour program for larger crews.

B. Role of Personal Maintenance (P.M.)

One concept carried through the entire study is that an adequate amount of personal maintenance time should always be baselined. Eight hours is set aside for sleep, though up to two hours less is expected to be adequate. Three periods a day of 2 hours each are also set aside for eating, hygiene, exercise, and housekeeping. Rest and recreation (R&R) is assumed to be adequately provided by the sleep period, swing time, short breaks between work tasks, eat and exercise periods, and one day off in seven, during which, as a matter of policy, no routine or nonessential work is performed. As crews get smaller we shall look for the impact of work loads on R&R. The assignment of 14 hours total per man for personal maintenance may result in large crews having short periods of spare P.M. time which can be used for additional, unrequired, short duration work tasks and in small crews using the spare P.M. time for a respite from assigned duties.

C. Solar Astronomy (A major, manned participation, SA&T activity)

As crews get smaller the time available for solar astronomy will decrease. Modification of the equipment, techniques, or both will be required if such observations are to be made with satisfactory frequency.

As envisioned for the 6-man Reference Mission, solar astronomy observations were to take place for two successive orbits (3 hours) on each of the three shifts. One might think that if round-the-clock operation were not baselined, the same amount of solar observation could be compressed into two shifts by simply lengthening the observation period in each shift to 4.5 hours. As we shall see, though, this is rarely possible. With the lengthy medical requirements, additional uninterrupted periods of 4.5 hours will be very rare; and the availability of two men for this length of time, to handle the higher work loads of active sun or flare studies, will be nonexistent.

While it is desired to have two men concurrently available for solar astronomy whenever possible, much of the time, during periods of quiet sun, only one man will be needed. Since the Quiet Sun task should not require a specialist, it can be alternated, for variety, between the two men, and the one not so occupied can perform other, swing-time tasks.

D. Role of a Computer

In addition to checkout and control of experiments and other systems, an onboard computer could keep track of regular, cyclical activities, such as personal maintenance and solar astronomy, so that crew availability could always be determined for a time and job of interest. In fact, this may be more representative of a computer's function than the usually assumed, detailed pre-mission or real time experiment scheduling.

The big proviso here, though, is that the computer would only be as useful as the crew made it. The crew might find keeping the computer informed about schedule changes and experiment status to be more bother than it was worth. The necessary input data would then be missing, unless the computer had an independent way of knowing who had how much sleep, how much film had been used, what experiments were removed from storage, completed, and returned, etc.

E. The Work Day

In this study a work day of so many hours means that a man is available for assignment to nonpersonal maintenance functions for that many hours per day. For example, eight hours for sleep and six hours for eating, hygiene, exercise, housekeeping, etc., leaves a work day of ten hours, the standard herein. This work time must cover scheduled and normally unscheduled events, but not, of course, emergencies. Normally unscheduled events include such things as solar flares (of importance less than 2) and noncritical repairs (includes most anticipated repairs).

If a man wishes, at some time, to work longer than his nominal work day, assuming the task is not of an emergency nature, independent attention (perhaps that of the crew commander would be sufficient) should be paid to his stage of fatigue and/or his previous work/rest history before he is allowed to do so. Besides the obvious advantages to his health in not being overstressed, he must be in condition to satisfactorily perform the minimum level of routine work tasks subsequently expected of him. While these routine tasks will probably require less time than his normal work day availability, they are essential to the success of the mission (since they consist of, for example, x hours of medical tests required for good statistical support of extending flight durations plus y hours of SA&T support necessary to keep the largely automated programs functioning properly). If he should desire to put in less than the required time (x+y) on any particular day, again independent authorization should be required.

IV. Multi-Disciplinary Missions with Different Crew Sizes

The capabilities of crews ranging in size from one man to seven (and up) to perform a multi-disciplinary earth orbital mission are summarized in this Section and examined in detail in the Appendix. A four-hour medical program is used for the principal analysis. The six-man crew and three-man crew are then reconsidered on the basis of the 2.5 to 3.3 hour, reduced medical program, described in Section IIIA.

Included in the Appendix are Figures depicting schedules, data summaries and comments in the same format as for the Reference Mission in Section II.

A. Six-Man Crew, Four-Hour Medical

This mission is essentially the same as for the Reference Mission, except that it is configured around a four-hour rather than a 4½ hour medical program, for ease of comparison of six-man crews with other crew sizes. The differences in detail between this and the Reference Mission can be seen by comparing the associated schedule and data sheets (Section II, Figure 3 and the Appendix, Figure 5).

One major change that could be accommodated by this size crew, with the slightly shorter medical program, is an increase in the component failure rate (reduced reliability requirement) to the order of two or three per week instead of one per week. Swing time, which had been increased by the reduced medical requirement, could then be used for the additional maintenance.

B. Other Size Crews, Four-Hour Medical

One-Man Crew

. A lengthy, solitary mission is probably feasible, but requires maximum practical safety measures and automation.

. The principal role of the crew is maintenance and data assurance.

. A busy work day (10-12 hours) would include certain tasks on regular, prearranged basis and others as time and preference permit.

. Medical experiments would be limited to simple, self-administered tasks.

. Monitoring of medical status is increased, but hardwire connections are avoided.

. An animal test program is likely, for data on extension of zero-g flight (and for companionship).

. Still, the rate of qualification of man for extended flights could suffer due to limited medical statistics.

Two-Man Crew

. The privacy requirement would be a major factor. It could be satisfied most on a staggered, but still partially on a simultaneous, sleep schedule.

. A staggered schedule provides more round-the-clock support, but requires more equipment modification for one-man operation. In either case more automation is required than for a six-man crew.

. A ten-hour work day now seems adequate. The schedule would be more structured than in the one-man case since the men must interact.

. Medical testing could be the same as for the six-man crew. Qualification of man for extended flight could be considerably faster than for one-man crew, but still is statistically limited.

Three-Man Crew

. Three men could undergo the same type or medical testing as a six-man crew.

. Nominal Active Sun observations could only be conducted on one shift per day, due to two-man-availability problem.

. The work schedule would be packed, since the Busy Day of this crew could come close to meeting the Minimum Day time requirements of a six-man crew (18 hours vs. 20 hours). Contingencies would be most unwelcome and disruptive, however.

. A three-shift sleep schedule (one man asleep on each shift, 1-1-1) provides less round-the-clock support of non-medical SA&T than a 2-0-1 sleep schedule.

. The 1-1-1 schedule may obviate the crew divisiveness problem commonly anticipated with a three-man crew.

. Extended-flight statistics are becoming acceptable.

Four-Man Crew

Two standard schedules and one unusual arrangement are examined:

. Four men on a 1-1-2 schedule provide more one-man time but no more two-man time than three men on a 1-1-1 schedule. The principal gain is more flexibility for handling interruptions by contingency activities.

. A 2-0-2 schedule provides enough two-man time to enable accomplishment of almost all the Minimum Day, non-medical activities of the six-man Reference Mission.

. The most interesting schedule would be a variant of one of the above (probably the first), in which the fourth man would be free to sleep and work when he felt like it and would be relieved of medical test requirements. This free-floater job position would provide the maximum possible contingency support. Also, rotating it among the crew on a weekly basis would serve each man as a welcome break from the possible monotony of space life, and would enable each man to be included in the medical statistics, since he would only miss one week in four of testing.

Five-Man Crew

. The schedule could resemble that of the six-man crew, except for the one man, on the average, usually left unassigned to connected type activities. The crew can handle the non-medical Minimum Day activity of the six-man crew, but not its Hectic Day.

. Again, a more interesting arrangement would probably be to have four of the men on a 2-0-2 schedule, and the fifth operating free-floater style, but sleeping when the others didn't, on the second shift. Rotation would again be used to provide diversion and interest to the crew.

Seven-Man (and up) Crews

Crews of larger size than six can have schedules with more flexibility, improved content, or both, compared to the Reference Mission. The number and variety of technical activities could be increased; or the degree of automation could be reduced, with more reliance on manned participation through onboard modification of experiment setups and procedures.

C. 2.5-3.3 Hour Medical

Six-Man Crew

On this schedule nine hours of swing time are effectively added to the nine previously available when 4.5 hours of medical testing per day per man were required. The benefits are as might be expected: Contingency activities are more readily supported, more SA&T can be preprogrammed or done on a real time basis, and crew interest should be stimulated by the greater variety of tasks possible. Also, more flexibility can be built into the scheduling of short duration tasks, such as Stellar Astronomy and Earth Looking; and specialist talents can be more readily brought into play, by having the same man perform repetitive or similar tasks in the same field.

Three-Man Crew

The Minimum Day is only one hour short of meeting the non-medical Minimum Day requirements of the Reference Mission. On the 2-0-1 schedule presented, two-man solar observation tasks could only be supported on one shift, though, instead of on the preferred three. A 1-1-1 schedule might allow two shifts of two-man support, as well as obviate the potential two-vs.-one psychological problem.

If the Active Sun or Flare modes could be designed for one-man operation, this crew could practically meet all the technical objectives of the Reference Mission.

V. General Analysis and Results

Efficiency or effectiveness, which we use synonymously, can be evidenced in at least the two following ways. There can be an actual shortening of the time it takes to complete tasks, or there can be an increase in the number of experiment hours completed in a specified time. The former implies flexible performance times for given tasks; the latter implies fixed performance times, but fuller utilization of the available work time. These processes are mutually exclusive and depend on the specific tasks being considered. As we shall see the latter is more amenable to analysis than the former.

We can inquire as to crew size effectiveness in both open-end and closed-end missions. By "open-end" we mean that the contemplated end of the mission is sufficiently remote to have no effect on current activities. The work load is always large compared to what can be done in a time of, say, several months. "Closed-end", then, means that the mission duration is sufficiently short and the payload sufficiently limited to have an effect on the planning and conduct of current activities. As a practical matter it may be necessary to treat intended open end, long duration, earth orbital missions as a series of closed-end missions, as limited by the periods and payload capacities of resupply flights and vehicles. For this study, however, we shall consider both type missions to be possible.

For the purpose of evaluating crew effectiveness, a useful simplification of the difference between the two types of missions is that: on an open-end mission, if efficiency goes up more work can be done; on a closed-end mission, if efficiency goes up the mission can be completed sooner. In both cases we attempt to continually provide work to fill the available time and crew capabilities; and we attempt to determine how much can be done per man and per period of time as a function of crew size. However, the two views of effectiveness mentioned earlier pose the following problems for a general analysis:

(1) Not all tasks are amenable to accelerated completion, e.g., certain astronomical and biological observations will require fixed or regular performance periods and times.

(2) Where activities can be speeded up, their early completion won't necessarily provide enough time for the performance of additional tasks. More leisure is thereby provided--but does this qualify for an improved effectiveness rating?

(3) Where efficiency goes down, in some cases, as where tasks can be interrupted without impact, partial credit could be given for partial performance. In other cases partial performance could be worthless. Then tradeoffs would be required between task completion and impacting personal maintenance or other-task time.

(4) A major problem with closed-end missions is that if tasks are completed faster than at the preplanned rate, unfilled gaps in the schedule will occur increasingly towards the end of the mission. This could be minimized by an initial oversupply of experiments, at a to-be-determined impact to storage and logistics capabilities. To some extent, non-idealized open-end missions would have the same problem with their logistics supply.

Someday, perhaps, a sophisticated approach to effectiveness evaluation can be developed. Perhaps it will offer a probability analysis of the chances that different crew sizes under various conditions would have of meeting a defined set of objectives or other performance criteria. For now, however, we offer the following admittedly artificial, but relatively simple scheme:

> Accomplishment for both open-end and closed-end missions is measured in terms of completion of so many "experiment hours" (useful hours of experimental measurements or experiment related work), whether done automatically or with manual assistance. (On a manned mission the successful performance of automated experiments is assumed to hinge on the assistance of man.) Accelerated performance is not considered; all tasks take fixed times and only increased utilization of available time is evaluated. An experiment hour performed on one job has the same value as an experiment hour on any other job, even if the job durations are different, their intrinsic worths are different, and their partial completions have or have no value.

Now we can inquire as to the rates at which different size crews complete experiment hours, the cumulative experiment-hour outputs as a function of time, and the total times required to complete any given numbers of experiment hours. In practice these will depend on the work tasks' manpower requirements, operating procedures, and schedulability, and will take into consideration priority (worth), timeliness (early or round-the-clock performance), and facility availability (everybody can't do medical tests or exercise at the same time). Certain fixed characteristics of the required tasks may interfere with full scheduling. We would prefer to be allowed to alter the tasks to match the available time and manpower. Both situations are examined in Figure 4, which graphically presents some qualitative aspects of the crew effectiveness problem.

Figure 4(a) represents the Reference Mission situation, where some of the activities necessary to meet the program objectives require two men for their performance. In that situation one- or two-man crews will be relatively ineffective at getting the desired work done. Point B at a crew size of about six (for which the experiment program was originally slanted) represents the maximum level of effectiveness. At that crew size all desired two-man tasks can be performed. The crew is still small enough so that the men do not get in each other's way; organizational problems do not yet begin to take hold.* With larger crews organizational factors become more influential, making their output rate asymptotically approach some lesser level, indicated by C on the curves.

Figure 4(b) shows the cumulative work output based on the rates of 4(a). Cumulative output increases slowly with small crews, rapidly through middle size crews, and then asymptotically to an intermediate, constant rate as crews get very big. If we want to know total output over a specified number of days with different size crews, and the availability of experiments is not a limiting factor, a simple conversion of the ordinate of Figure 4(b) to "experiment hours per the number of days of interest" would permit that interpretation.

Figures 4(c) and (d) show what happens if we permit experiments to be modified so that no more than one man is required for any activity, including medical testing. While the effectiveness of small crew performance goes up, it will still be less than average if we regard Modified Watch and Repair as distinct from experiment support. Again, effectiveness would improve as crew size increased, since the operational tasks were being shared among more men, until the organizational

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* As crews and experiment programs grow larger, the increasing likelihood of conflicting demands for equipment, space, and computer and other means of experiment support will create a need for one or more men in separate management roles. While the management personnel contribute to the orderly conduct of onboard activities, their subtraction from the manpower pool will result in some loss of average time per man applied to experiment tasks. This or any other decrease in efficiency resulting from an increasingly complex organization is what we mean by "organizational problems."

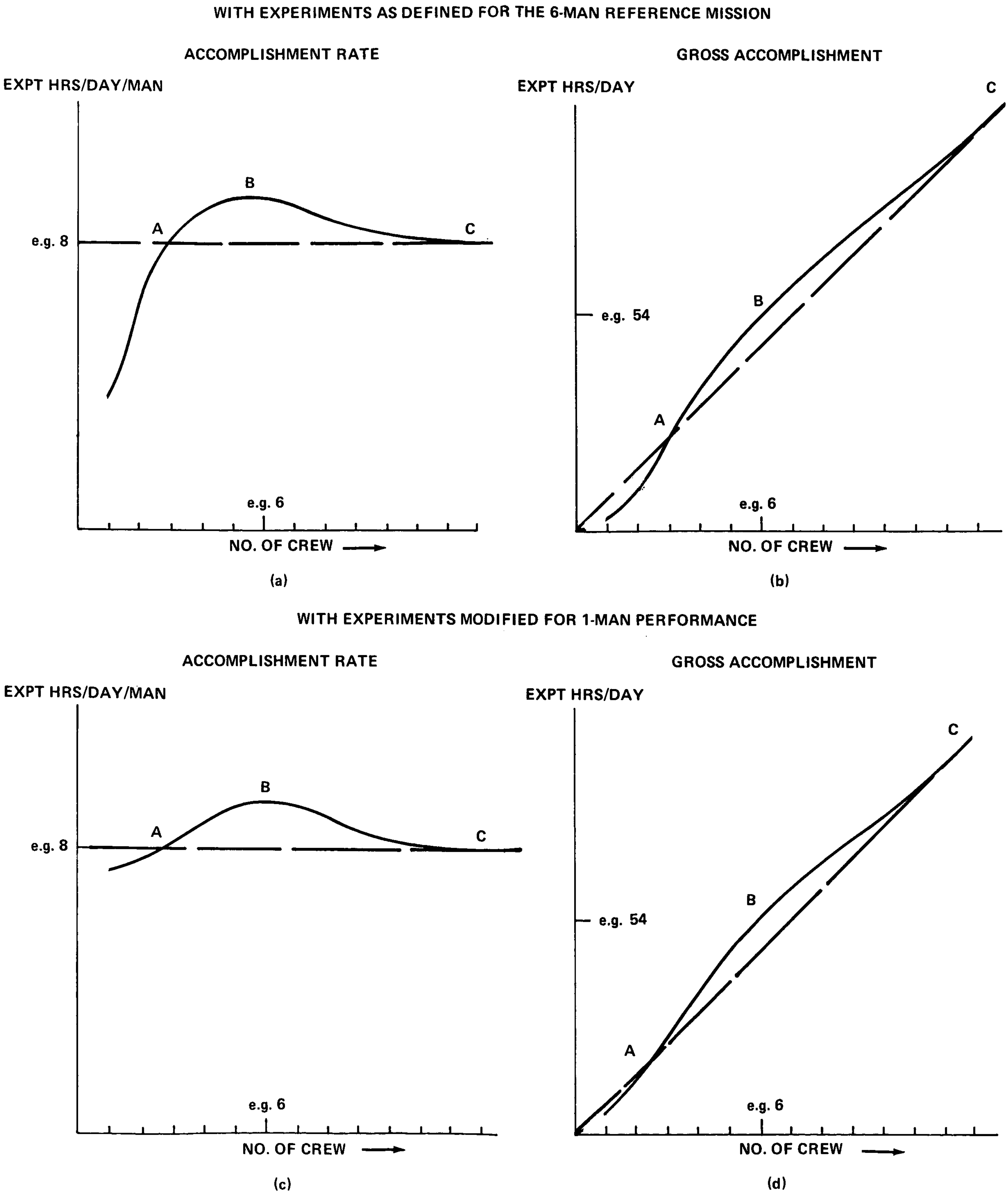
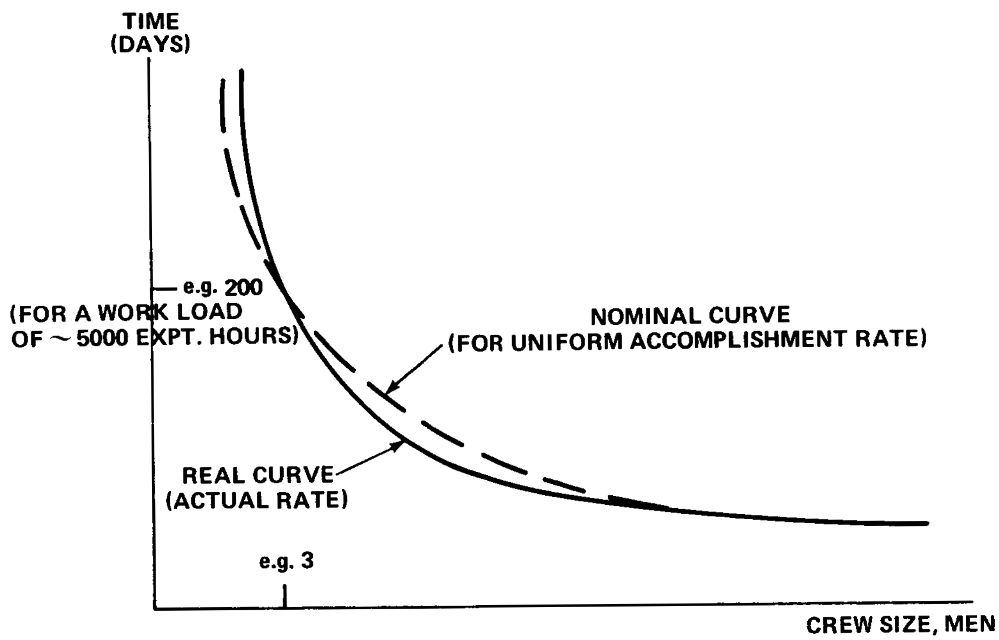


FIGURE 4-QUALITATIVE PERFORMANCE CURVES

FIG. 4

factors mentioned earlier took over. On the other hand, Modified Watch and Repair could be treated as experiment activities, since they enable performance of the experiments through equipment maintenance and data assurance. This would cause the accomplishment curve in 4(c) to begin somewhere above the asymptote rather than below it.

The times necessary for different size crews to accomplish equal work loads can be derived from 4(b) or (d) and are shown qualitatively in the following sketch.



The "nominal curve" is such that the time should decrease by a factor of two as the crew size doubles. The "real curve" shows a crossover point, beyond which the crew is more efficient and before which it is less efficient than nominal. For a given work load, degree of automation, and task complexity (number of men required per task), the performance time required will decrease with increasing crew size in the manner shown. However, the accomplishment of large workloads in short times is limited by two obvious factors: the capacity of the space station to accommodate the necessary crew sizes and the finite minimum times which tasks require for their completion.

The degree of automation is an important consideration in determining crew size. Increased automation will permit smaller crews for any given work load. There would then have to be a tradeoff of automation costs, with their attendant costs of designing for increased reliability, versus crew and support requirements costs to meet the same objectives. This problem would come up were we to consider modification of the solar astronomy requirements or procedures for accomplishment by smaller crews, as suggested earlier.

Furthermore, we note that as crew size diminishes certain activities become less precisely defined as to content and duration. As the demand for the limited available time increases, activities are reduced more and more to their essentials or are modified to meet tighter time budgets; e.g., Modified Watch can begin to include other unrelated but short duration activities, such as calibration of stellar or earth looking equipment; solar observations can become more limited in scope, so that one orbit may be considered satisfactory for obtaining useful information whereas before two orbits were required; solar experiments may be modified so that one man can perform all the necessary operations during active-sun and flare periods whereas before two men were required. Also, tasks become less professional in nature and more routine, so that specialization may not be required and each man can operate effectively in more areas.

Finally, we repeat the obvious but important observation that a tradeoff must be made between crew size and the rate of qualification of man for flights of extended duration. The urgency of such qualification tests will of course be strongly affected by specific plans for manned planetary missions.

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1015-SLP-rghe

Attachments
References
Appendix

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2. Penn, S. L., "Mission Sequence Plan for a Multi-Disciplinary Earth Orbital Space Station - A Preliminary Report," Bellcomm TM-68-1011-9, Dec. 27, 1968.

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APPENDIX

Multi-Disciplinary Missions With Different Crew Sizes

I. Schedules and Data Summaries

The two principal devices for presenting the features of the multi-disciplinary programs of different size crews are the Crew Inflight Schedule and the Data Summary sheets. Since these forms are to be used in conjunction with the discussion material that follows, they are explained first. These portrayals of individual assignments enable us to consider not only whether total time allottments permit certain activities to be scheduled, but also whether individual availability is appropriate. In addition they permit us to begin considering the possible role of specialists in the task assignments, i.e., whether certain men can or should end up doing certain type tasks more than the others. The formats chosen enable a practical assessment of how well balanced the programmed activity is and whether the time left between tasks is ample for work breaks or extra activities.

The schedules permit improved visibility and application of certain mission constraints, such as the ephemeris. Figure 3 is a case where after-the-fact preparation of a schedule for the Reference Mission revealed certain inconsistencies of task assignments with the ephemeris, as noted in the comments of the summary sheet for that Figure. Suffice to point out here that care must be exercised to schedule earth looking activities during daylight and stellar astronomy during dark side passes (until experience dictates otherwise). If each orbit is assumed to start in the middle of a dark side pass, to allow preparation for solar astronomy observations, then earth looking should be scheduled for the middle of an orbit and stellar astronomy near the beginning or end.

Each schedule is followed by a data summary table, which provides a view of the individual roles in different activities. The table is followed by comments on interesting features of the schedule, table, or both.

The "Minimum Day" concept as used in the summaries and elsewhere in this report is that of a day which produces the basic, minimum acceptable data return in the different disciplines to justify the mission. The day must be scheduled so that astronaut time is available to support the frequent need for higher levels of manned activity in top priority experiments, such as Active Sun or Flare observations. When those higher levels of activity are not required, additional work on other SA&T short duration tasks can be performed. The Minimum Day plus those "swing-time" activities constitute a "Busy Day". The swing-time tasks should be of such a nature that they can be readily suspended, preferably with little impact, when the need for higher priority activities occurs. The presence of the latter transform a Busy Day into a "Hectic Day".

Rest and Recreation (R&R), as accounted for on the data sheets, is the unusued available work time on a Busy Day (10 hours assumed available for work).

Data Assurance (DA), while not broken out from SA&T in the summaries, is activity which enables the performance of experiments even though not directly contributing to them. Modified Watch is the prime example. Calibration of experiment equipment, included in the astronomy and earth looking tasks, and film processing are harder to classify, and probably lie near the borderline between DA and SA&T.

The solar astronomy and bioscience activities when used herein as task activity designations rather than generic descriptors are primarily considered as substitutes for the Quiet Sun and Attend Specimens activities respectively, when the latter two can not or should not be performed in the manner intended for the Reference Mission, for which they were defined. Bioscience also includes several additional activities which can be performed during swing-time periods, if desired.

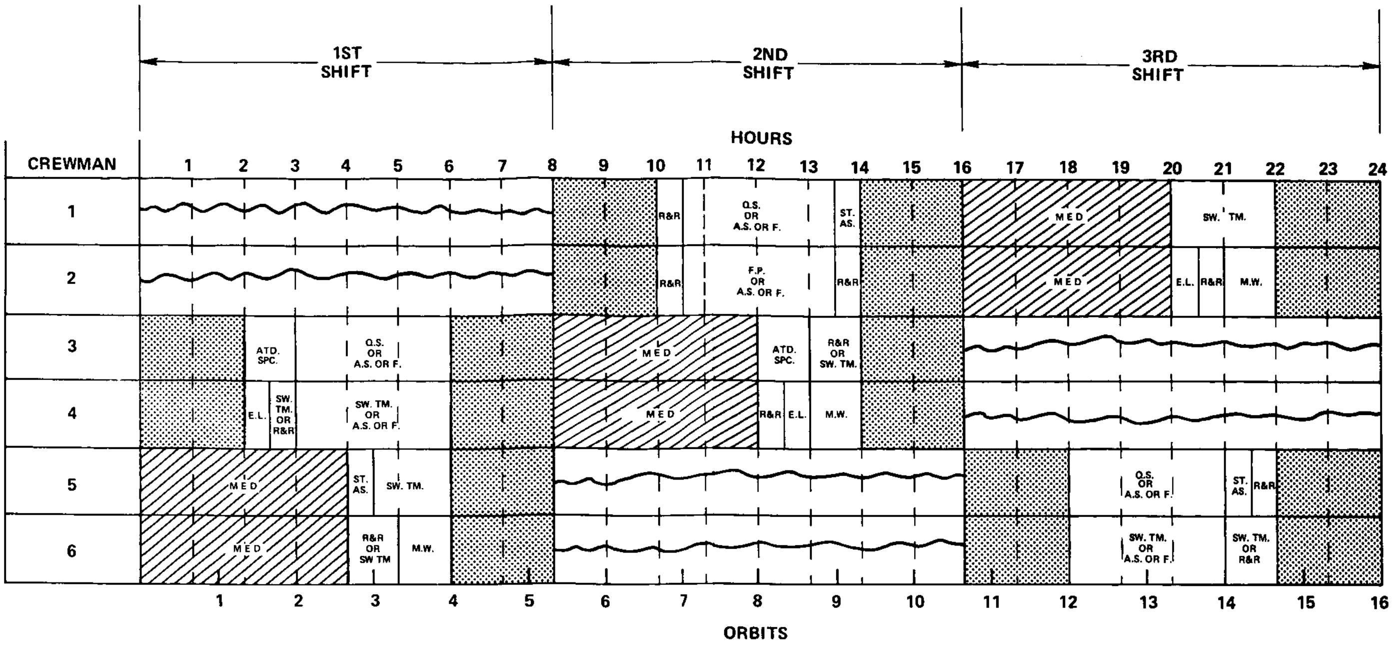
Comparative statements on the summary sheets are with respect to the Reference Mission unless otherwise stated.

II. Discussion

A. Six-Man Crew, Four-Hour Medical (Figure 5)

Essentially the same as for the Reference Mission, discussed earlier in the text and at length in Reference 2. Some differences are pointed out in the comments on the data summary sheet for Figure 5. One major change that could be accommodated by this size crew, with the slightly shorter medical program, is an increase in the component failure rate to the order of two or three times per week instead of one per week, the swing time now being used increasingly for maintenance.

FIGURE 5 - CREW INFLIGHT SCHEDULE
(4 HR MED. PROGRAM)



LEGEND

SLEEP

PERSONAL MAINTENANCE
(EAT, EXERCISE, HYGIENE, HOUSEKEEP)

MEDICAL EXPERIMENTS
S = SUBJECT
O = OBSERVER
L.T. = LABORATORY TECHNICIAN

WORK AVAILABILITY

A.S. OR F.	= ACTIVE SUN OR FLARES
Q.S.	= QUIET SUN
SOL. AS.	= SOLAR ASTRONOMY
ST. AS.	= STELLAR ASTRONOMY
E.L.	= EARTH LOOKING
F.P.	= FILM PROCESSING
M.W.	= MODIFIED WATCH
ATD. SPC.	= ATTEND SPECIMENS
BIO.	= BIOSCIENCE
SW. TM.	= SWING TIME
R&R	= REST & RECREATION

FIG. 5

DATA SUMMARY FOR FIGURE 5 (HOURS PER ACTIVITY)
6-MAN CREW (4 HR. MED. PROG.)

CREWMAN	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	TOTAL MIN. DAY	TOTAL BUSY DAY	R&R
1	–	4	3		½	–	–	–		2	7½	9½	½
2	1	4	–		–	½	3	–		–	8½	8½	1½
3	–	4	3		–	–	–	2(1)		–	9	9	1
4	1	4	–		–	1(1)	–	–		3½	6	9½	½
5	–	4	3		1(1)	–	–	–		1½	8	9½	½
6	1	4	–		–	–	–	–		4	5	9	1
TOTAL	3	24	9		1½	1½	3(3)	2		11(2)	44	55	5(2)
										MED	-24	-24	
									SA&T	(+D.A.)	20	31	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) Compared with Reference Mission, this schedule makes more effective use of men by occasionally having "specialist" perform repetitive tasks in ST. AS., E.L., and ATD. SPC.
2) The extra 2 hours, of SW. TM. and 1 hour of R&R (compared with Reference Mission) = the 3 hours of MED. time saved.
3) Should A.S. or F. preclude routine performance of F.P., it would be done during SW. TM. as convenient. With an active sun, there would only be 5½ hours of SW. TM. and 4½ hours of R&R, with the longest period of SW. TM. being 2 hours; so F.P. should be designed for interrupted

B. Other Size Crews, Four-Hour Medical

One-Man Crew* (Figure 6)

While a one-man crew may be less than desirable from social and contingency standpoints (loneliness, no backup or assistance), there is no reason to assume that a man cannot be motivated and trained to perform a lengthy, solitary mission with adequate safety and abort procedures (except, perhaps, for injury). On a one-man mission experiments would be automated to the maximum extent possible, with provision for manned maintenance. The Reference Mission failure rate of one per week is probably acceptable. Redundancy of safety critical features is most essential here.

The medical program would be limited to tests capable of being self-administered and not requiring an observer. Some laboratory technician time is probably acceptable. Medical status monitoring is probably needed more than with larger crews, and would provide the crewman with assurance that somebody down there cared and was watching over him. Monitor devices would have no hardwire connections, but would telemeter data to onboard storage and transmitter equipment.

A bioscience program with animal subjects might be even more important than with large crews. Such a program would provide companionship and external interests to the crewman as well as data on extension of zero-g flight (the animal could stay in orbit when the crew is rotated).

The crewman could perform limited support to a solar astronomy program of modified character, e.g., the Quiet Sun mode for a few hours a day; but equipment design and/or operation would have to be modified if manned support were also required for Active Sun and Flare modes, since these are currently seen as needing two men. Routine round-the-clock manned support of experiments would, of course, not be possible; but solar flares of importance two or greater might be worth disrupting sleep for because of their relative importance and infrequent occurrence (about once a week during the 1975 time frame, i.e., once every 3 weeks during his 8 hour sleep period).

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* While consideration of a one-man crew may appear mostly academic at the moment, there may be times in the space program when one-man missions take on more significance than can be clearly seen now (e.g., one man in CM doing SA&T while his crewmates conduct extended lunar surface exploration; or earth orbital simulations of one-man landings on Mars). For this reason and for the sake of completeness in our analysis the discussion of the one-man crew is pursued.

Modified Watch would be conducted twice a day (items checked each time could be different) instead of three times as on the Reference Mission.

In conclusion, it is estimated that a crew of one would provide a considerable measure of data assurance to a complement of highly automated experiments, but those activities currently requiring two men for their performance would have to be appropriately modified or deleted. Modification is, probably, generally possible, though some medical tests would require deletion (e.g., those where an observer is essential). Equipment down-times would probably be increased, since, while most repairs or replacements may be designed for one man, the lack of an assistant can, on occasion, markedly slow things up. Suffering most would be the pace at which man is qualified for long term space flight. Followup flights would include several repetitions of previous durations before extension could take place, the statistical basis for drawing conclusions being weak because of the small sample sizes.

FIGURE 6 - CREW INFLIGHT SCHEDULE - 1 MAN
(SPECIAL MED PROGRAM)

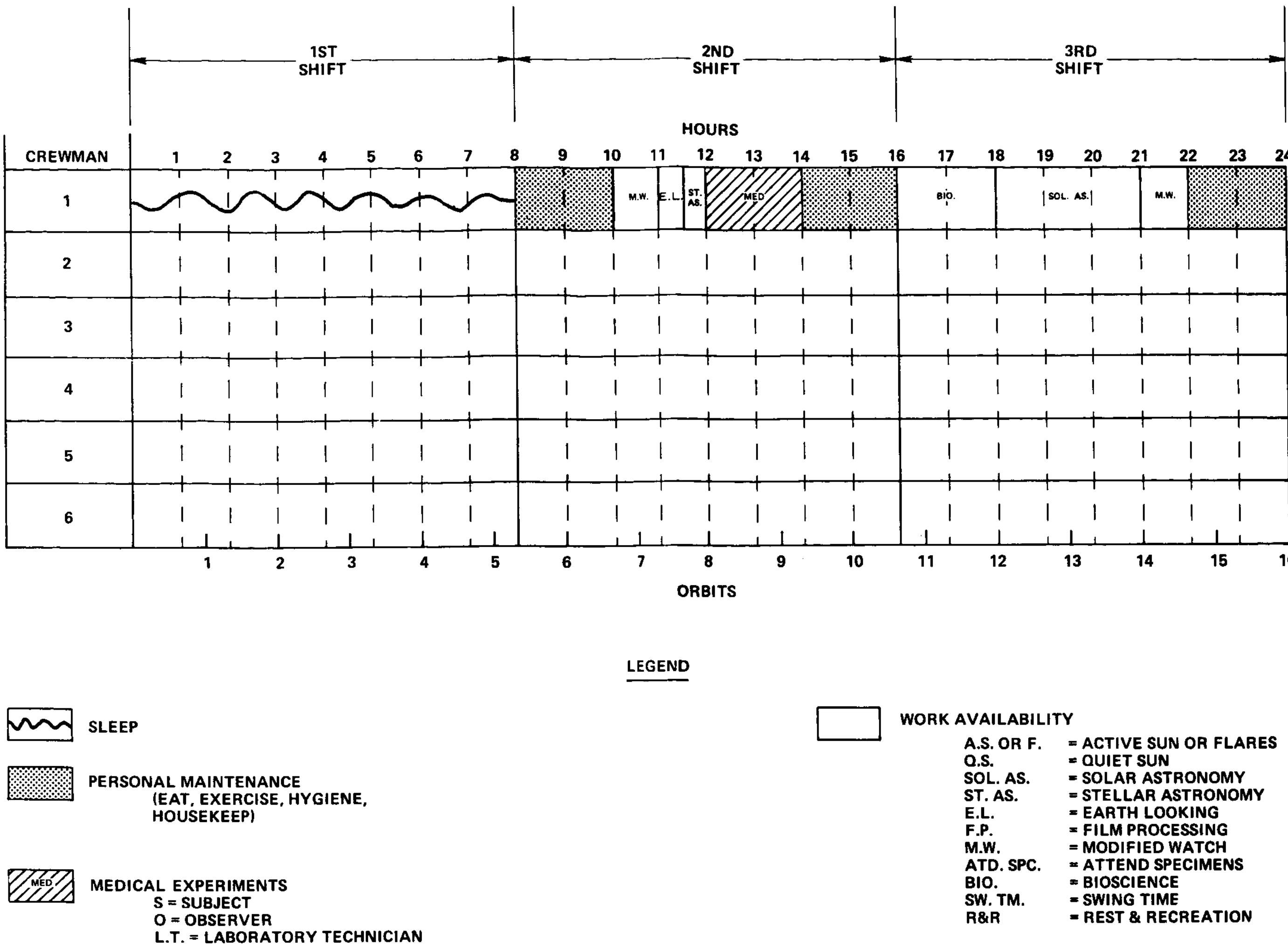


FIG. 6

DATA SUMMARY FOR FIGURE 6 (HOURS PER ACTIVITY)
1-MAN CREW (SPECIAL MED. PROG.)

CREWMAN	ACTIVITY										TOTAL		
	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	MIN. DAY	BUSY DAY	R&R
1	2	2		3	½	½	?(1)		2	-	10(2)	10(2)	-
										MED.	- 2	- 2	
										SA&T (+D.A.)	8	8	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) F.P. may present special problems in view of restricted available time. Either it can be done, at times, in place of SOL. AS. or E.L. and ST. AS., or it can be suspended in favor of hard copy return at crew exchange time.

2) Outstanding feature, of course, is the lack of spare time in the nominal day, minimum and busy.

Two-Man Crew (Figures 7 and 8)

On a long mission the need for periods of privacy would seem to favor dissimilar sleep schedules for a crew of two (Fig. 7). If we assume a 24 hour day and 3 eight hour shifts, we can see each man sleeping and having R&R on a shift different from his coworker's and sharing a four hour work period and two Personal Maintenance periods with his fellow crewman on the remaining shift. This would allow each man to perform 4-6 hours of work while the other was sleeping.

The period of common work activity could now be used to perform medical experiments in the same manner as in the Reference Mission. The difference is that with a two-man crew 1/3 as many men would be qualified for space flight at a time. Statistics being poorer, we might take longer to commit men to longer flights. If, however, we were willing to assume that astronauts are sufficiently alike physically to make favorable inferences from successful limited manpower performance, we could allow one man to stay up at crew exchange time and bring back the other for testing, thus achieving longer stay times faster than with one-man crew programs. This assumes that one man failures are not as significant as successes, since a failure could be due to adverse factors which had existed all along, but were not discovered in previous tests.

On this schedule all activities other than medical would have to be designed for one man performance, thus requiring modifications similar to those of the one-man crew case. SA&T experiment support would still not be round-the-clock; but support for 2/3 day would be feasible, and repairs could also be more normally effected, two men being available if required. As a practical matter, Modified Watch would still only be done twice a day, during the one-man activity periods.

A ten-hour workday is now seen as adequate, since the companionship factor would make it less likely that the men become preoccupied with themselves during leisure time. Since the men's schedules must now interact, less freedom in their work planning would be allowed than in the single man case.

Of course, it's always possible that a concurrent sleep program can be worked out which would still have a split work schedule providing some privacy to the men (Fig. 8). Now, however, with one shift predominately medical and another entirely sleep, only one shift would be available for a substantial level of other experiment support. This would permit performance of active-sun or flare observations without modification of experiment equipment and procedures, though.

In conclusion, the activities of a two-man crew would be more like those of a six-man crew than a one-man crew. Psychological aspects would be closer to normal. Medical testing would be normal, though with reduced statistics. Other experiments would have to be modified for one-man performance if we wanted a staggered sleep schedule. There would be little or no time for unscheduled, unconnected activities (e.g., short duration, infrequent physical science), perhaps some impact to film processing or selection, and only 1/3 to 2/3 of the day availability for routine support to SA&T.

FIGURE 7 - CREW INFLIGHT SCHEDULE - 2 MEN (1ST OPTION)
(4 HR MED PROGRAM)

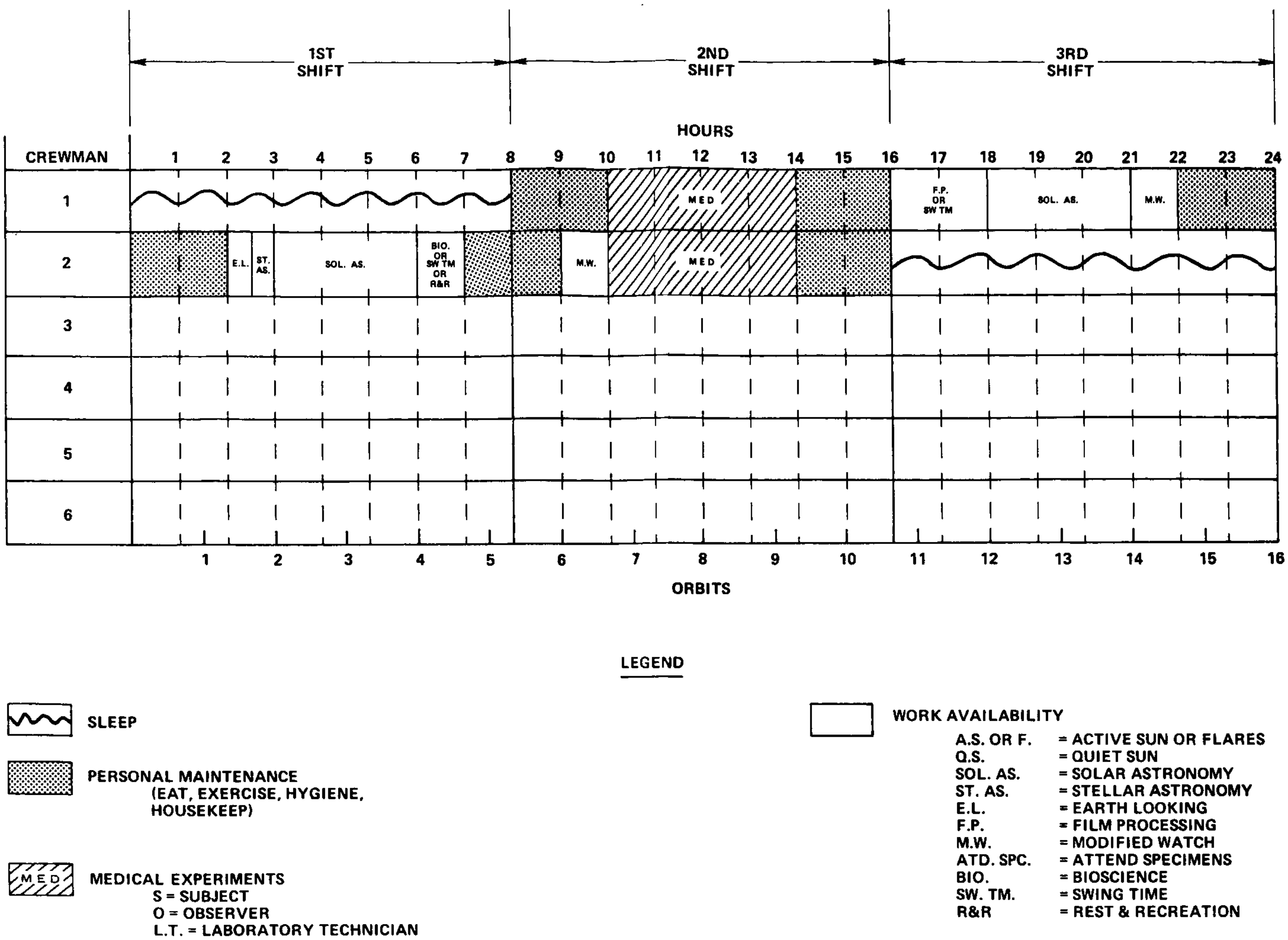


FIG. 7

DATA SUMMARY FOR FIGURE 7 (HOURS PER ACTIVITY)
2-MAN CREW (4 HR. MED. PROG.)
(1st OPTION)

CREWMAN	ACTIVITY										TOTAL		
	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	MIN. DAY	BUSY DAY	R&R
1	1	4		3	-	-	2		-	-	10	10	
2	1	4		3	½	½	-		1	-	10	10	-
TOTAL	2	8		6 (2)	½	½	2 (1)		1	-	20 (3)	20 (3)	-
										MED.	- 8	- 8	
									SA&T (+D.A.)		12	12	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) 2 hrs. of F.P. may be adequate in view of the reduced solar observations.

2) SOL. AS. is indicated as the ongoing activity instead of Q.S. since a modification of the equipment and/or techniques is required to enable 1 man to make active sun or flare observations.

3) Again we note the lack of spare time in the nominal day.

FIGURE 8 - CREW INFLIGHT SCHEDULE - 2 MEN (2ND OPTION)
(4 HR MED PROGRAM)

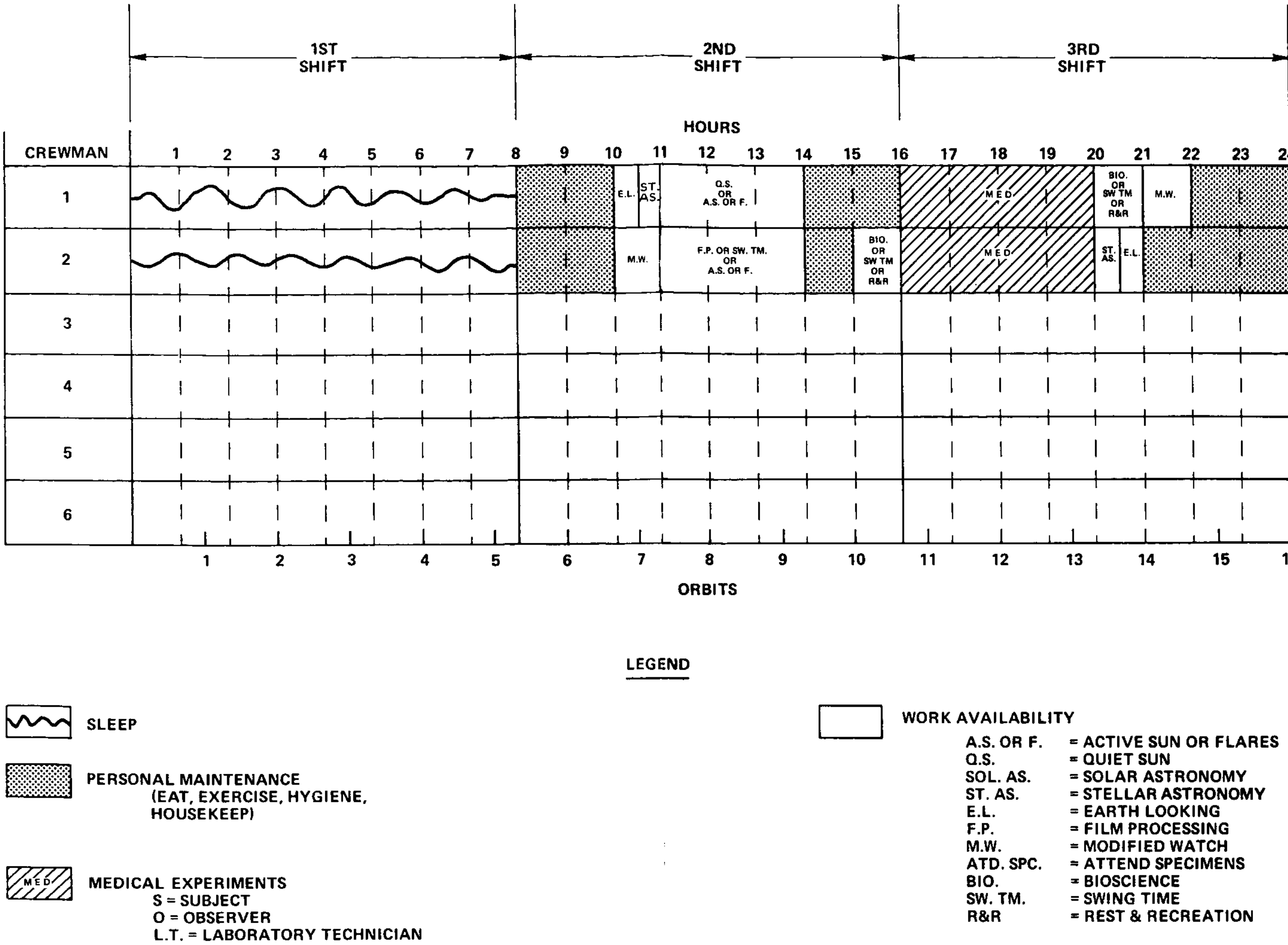


FIG. 8

DATA SUMMARY FOR FIGURE 8 (HOURS PER ACTIVITY)
2-MAN CREW (4 HR. MED. PROG.)
(2nd OPTION)

CREWMAN	ACTIVITY: M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	TOTAL: MIN. DAY	BUSY DAY	R&R
1	1	4	3		½	½	-		1	-	10	10	-
2	1	4	-		½	½	3		1	-	10	10	-
TOTAL	2	8	3		1	1	3 (1)		2	? (2)	20 (3)	20	
										MED.	- 8	- 8	
								SA&T (+D.A.)			12	12	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) 3 hrs. of F.P. is probably excessive in view of the reduced level of SOL. AS. activity compared with that of 6-man crew.

2) The amount of SW. TM. could be as high as 5 hrs., if daily F.P. is not necessary and if routine tasks, such as indicated BIO., are not required. It probably pays to leave each man at least 1 hr. of SW. TM. instead of regular BIO., so that repairs and unexpectedly large contingency work loads can be handled. This time might even serve for R&R if warranted.

3) Presence of SW. TM., as in (2) above, would result in corresponding lowering of minimum day total.

Three-Man Crew (Figures 9 and 10)

Consideration of this size crew provided convincing proof to the author that estimates of the capabilities of crews of different sizes without preceding or concurrent preparation of actual schedules can be misleading or in error. Without going into the detail, it had seemed reasonable that, with a three-man crew, a three-shift sleep schedule having one man asleep and two available for work at any time would provide more efficient round-the-clock SA&T support than having two men asleep on one of the shifts and, hence, only one man available for work at that time.

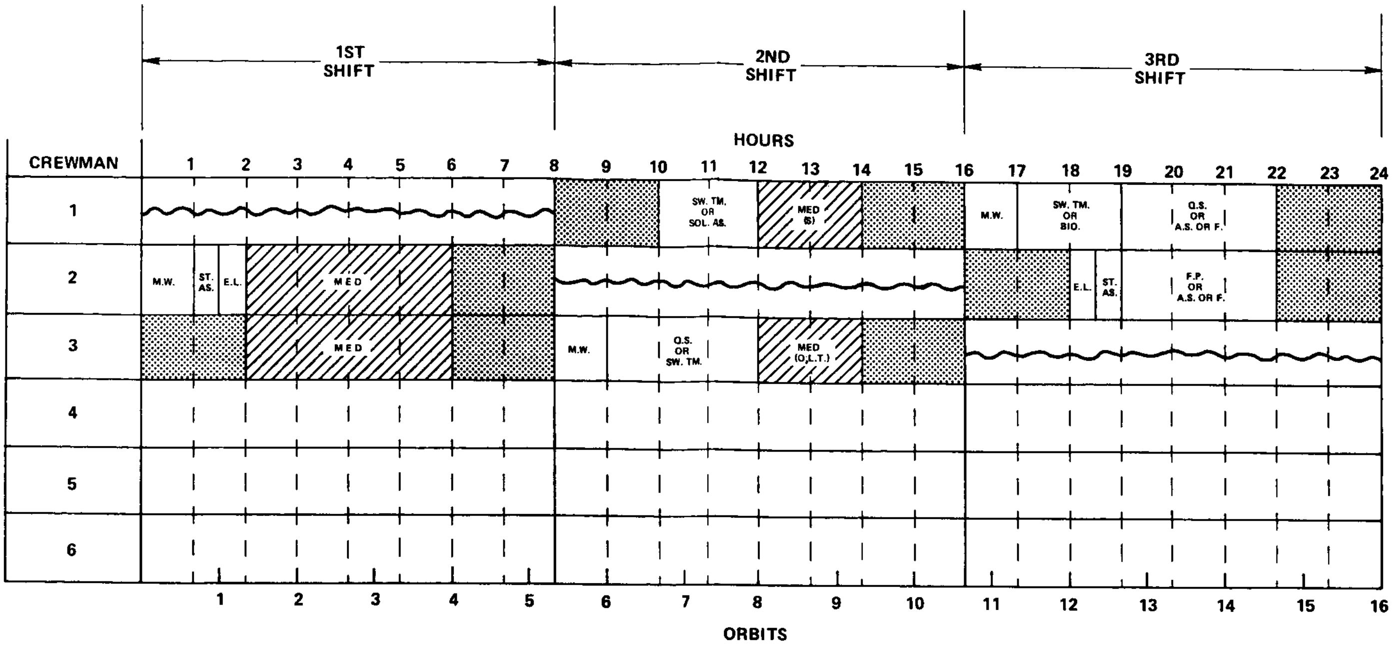
As Figures 9 and 10 show, that is not the case. On the three-shift sleep schedule (Fig. 9), with ten work hours per man per day, in order to have even one three-hour period of two-man availability for solar astronomy (three or which are scheduled on the Reference Mission), the following scheduling is required. One shift must be devoted primarily to fulfilling the medical test requirements of two of the men, one of whom would have about two additional hours of work availability that shift. The next shift could see the third man's medical requirements taken care of, with support from his awake companion; in addition to which there would still be about two hours available for dual support of SA&T and another two hours of single man availability. The third shift would have one man available alone for two hours and, then, two men available for four hours, during three of which the only standard solar astronomy could be done. However, if the solar astronomy requirements could be reduced so that two sunlight passes (rather than two complete orbits) were sufficient, the schedule might be adjusted to have those two passes occur in the two-hour, two-man availability period in the second shift (enabling Active Sun and Flare modes to be supported then, too.) If solar astronomy had sufficient priority and could be modified and performed as indicated, the swing-time support of other SA&T would be accordingly reduced.

No R&R is shown on the schedule since we are attempting to do as many of the Reference Mission tasks as possible. The sleep period allotment of eight hours plus the one day off in seven might cover the need for leisure. Modified Watch would be feasible three times per day. Repairs, though infrequent, would be disruptive, interfering with solar observations or other activities about once a week. Earth looking and stellar astronomy could each be supported twice a day versus three for the Reference Mission. Adequate film processing and selection could be done concurrently with Quiet Sun modes or during swing-time periods.

The 2-0-1 man sleep schedule of Fig. 10 also provides staggering of the medical activities and a single two-orbit, two-man-available solar observation period. Round-the-clock SA&T support is more available here than with the three-shift sleep schedule, though it is sporadic. A disadvantage of the 2-0-1 schedule is that it would be more likely to promote crew divisiveness. Three men asleep at the same time clearly eliminates round-the-clock support.

In conclusion, life for a three-man crew could be hectic; round-the-clock SA&T support would be feasible but not nearly as extensive as for a larger crew; and better statistics than for smaller crews would be gathered for extended flight. While, for long flight durations, the three-man crew is popularly believed to be relatively psychologically unstable (two vs. one splits expected), the three-shift sleep schedule of Fig. 9 might obviate that problem, since no more than two men are together at any one time and the different pairings spend equal time together.

FIGURE 9 - CREW INFLIGHT SCHEDULE - 3 MEN (1ST OPTION)
(4 HR MED PROGRAM)



LEGEND

SLEEP

PERSONAL MAINTENANCE (EAT, EXERCISE, HYGIENE, HOUSEKEEP)

MED MEDICAL EXPERIMENTS
S = SUBJECT
O = OBSERVER
L.T. = LABORATORY TECHNICIAN

WORK AVAILABILITY

A.S. OR F. = ACTIVE SUN OR FLARES
Q.S. = QUIET SUN
SOL. AS. = SOLAR ASTRONOMY
ST. AS. = STELLAR ASTRONOMY
E.L. = EARTH LOOKING
F.P. = FILM PROCESSING
M.W. = MODIFIED WATCH
ATD. SPC. = ATTEND SPECIMENS
BIO. = BIOSCIENCE
SW. TM. = SWING TIME
R&R = REST & RECREATION

FIG. 9

DATA SUMMARY FOR FIGURE 9 (HOURS PER ACTIVITY)
3-MAN CREW (4 HR. MED. PROG.)
(1st OPTION)

CREWMAN	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	TOTAL MIN. DAY	TOTAL BUSY DAY	R&R
1	1	2	3		-	-	-			4	6	10	-
2	1	4	-		1	1	3			-	10	10	-
3	1	6	3		-	-	-			-	10	10	-
TOTAL	3	12	6 (1)	? (2)	1	1	3 (3)		? (4)	4 (5)	26	30	-
										MED.	-12	-12	
									SA&T (+D.A.)		14	18	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) Requires sufficient flexibility of Q.S. mode to permit starting at different parts of an orbit, otherwise only 3-4½ hrs. would be available, depending on whether single orbit data will meet P.I.'s requirements.

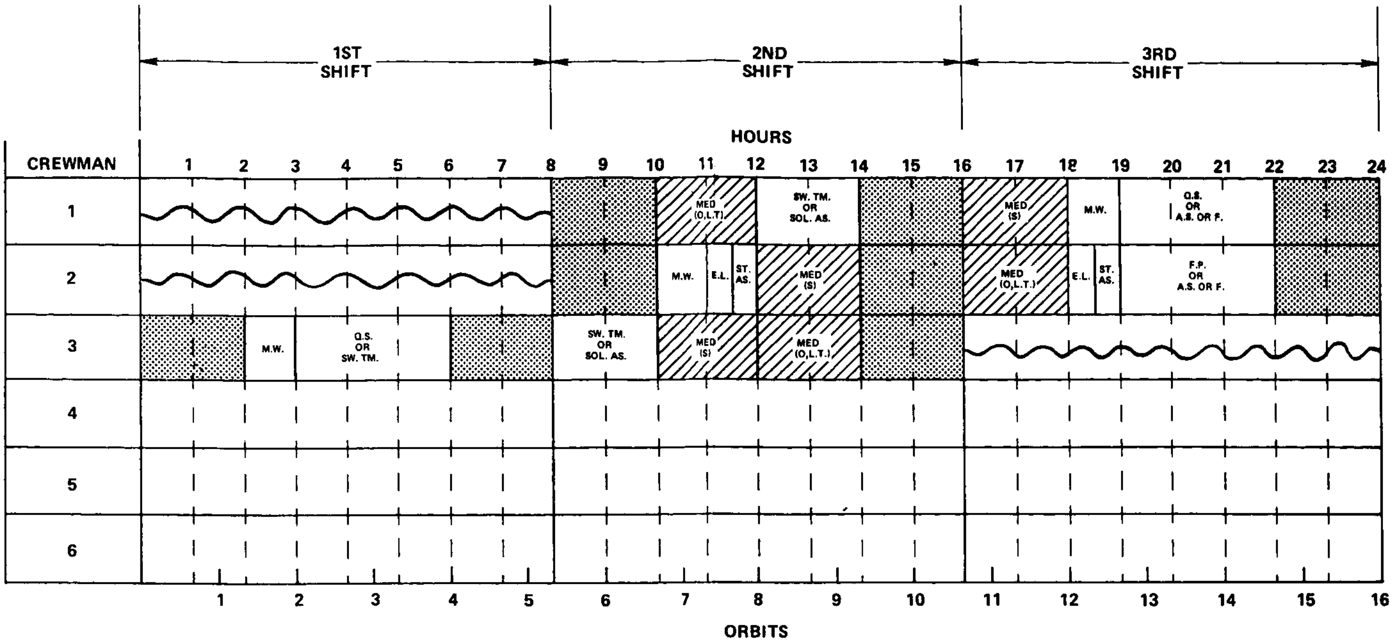
2) Could be 2 hrs. if 1 1/3 orbits (2 bright side, 1 dark side passes) per run are acceptable to SOL. AS. people. Also, might be used for A.S. or F. support of C.M. #3's concurrent solar observations (see schedule).

3) 3 hrs. of F.P. may be excessive, due to reduced SOL. AS. load compared with 6-man crew.

4) The option for 2 hrs. of BIO. is shown in the schedule to show that, depending on priorities, some activity in this area could be carried on.

5) 7 hrs. during active sun periods if 1-man solar observation not acceptable then (C.M. #3, 2nd shift); seems more likely that C.M. #1 would work with him, though, during his 2 available SW. TM. hrs.

FIGURE 10 - CREW INFLIGHT SCHEDULE - 3 MEN (2ND OPTION)
(4 HR MED PROGRAM)



LEGEND

SLEEP

PERSONAL MAINTENANCE (EAT, EXERCISE, HYGIENE, HOUSEKEEP)

MEDICAL EXPERIMENTS
S = SUBJECT
O = OBSERVER
L.T. = LABORATORY TECHNICIAN

WORK AVAILABILITY

A.S. OR F.	= ACTIVE SUN OR FLARES
Q.S.	= QUIET SUN
SOL. AS.	= SOLAR ASTRONOMY
ST. AS.	= STELLAR ASTRONOMY
E.L.	= EARTH LOOKING
F.P.	= FILM PROCESSING
M.W.	= MODIFIED WATCH
ATD. SPC.	= ATTEND SPECIMENS
BIO.	= BIOSCIENCE
SW. TM.	= SWING TIME
R&R	= REST & RECREATION

FIG. 10

DATA SUMMARY FOR FIGURE 10 (HOURS PER ACTIVITY)
3-MAN CREW (4 HR. MED. PROG.)
(2nd OPTION)

CREWMAN	ACTIVITY										TOTAL		
	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	MIN. DAY	BUSY DAY	R&R
1	1	4	3		-	-	-	-		2	8	10	-
2	1	4	-		1	1	3	-		-	10	10	-
3	1	4	3		-	-	-	-		2	8	10	-
TOTAL	3	12	6 [1]	? [2]	1	1	3 [3]	- [5]		4 [4]	26	30	-
										MED.	-12	-12	
										SA&T (+D.A.)	14	18	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) Requires sufficient flexibility of Q.S. mode to permit starting at different parts of an orbit.

2) Could be 4 hrs. if 1 1/3 orbits per run are acceptable to SOL. AS. people.

3) 3 hrs. of F.P. may be excessive, due to reduced SOL. AS. load.

4) Could be 7 hrs., as with 1st option.

5) Not performed during available SW. TM., since it requires doing twice a day @ 8-10 hrs. separation. Other BIO. could be done, though, if sufficiently short ($\lesssim$ 2 hrs.).

Four-Man Crew (Figure 11)

A four-man crew could operate with three men on a staggered, round-the-clock sleep schedule, as in Figure 9, and the fourth man sleeping on a shift where his absence would be least felt. In this case he would sleep on the third shift, when the rest of the crew was least occupied with medical duties. He would perform his medical activities during the second shift, coordinating them with the, as yet, untested number one man, thus freeing the other awake man, number three, from a repeat of medical support tasks. This would increase the amount of one-man time available for solar studies, enable the less eratic performance of film processing and selection, increase the available swing time, and enable repairs to take place sooner and more conveniently. It would not increase the time available for two-man activities, such as Active Sun or Flare observations. It would, however, increase the choices as to whose Personal Maintenance activities could be most readily disrupted, should a special work requirement warrant it.

Another possible arrangement is shown by Figure 11, in which we build from the three-man crew, second option (Fig. 10), and have a pair of men sleeping on the third shift as well as the first. On this schedule there is more two-man time than in the first plan. We note that, now, the minimum nominal tasks of a six-man crew could be accomplished, except for solar astronomy during one shift per day and except for the medical qualification of a fifth and sixth man. Our Busy Day and Active Sun and Flare support capabilities would not be as comparable, however.

It would probably be more interesting to put the fourth man on a completely unscheduled program, sleeping when he felt like it, working when he felt like it, at the most essential or useful tasks of the moment, and free from the performance of medical experiments (though having more monitorship of his essential medical status parameters, on a non-interference basis preferably). There being plenty to do onboard, he'd probably keep quite busy. This role of the fourth man, being perhaps more interesting than those of the other men, could be rotated among the crew on a weekly basis, and would serve as a welcome break from the possible monotony of space life. This would allow each man three out of four weeks for routine medical experiments, so that he could still be included in the statistical medical qualification of man for extended flight.

In the fixed four-man schemes we would have about four manhours per day for swing-time activities, and we could conveniently do repair work within a day after the need arose. In the one-man-floating scheme we'd have more flexibility for spontaneous contingency support.

FIGURE 11 - CREW INFLIGHT SCHEDULE - 4 MEN (2ND OPTION)
(4 HR MED PROGRAM)

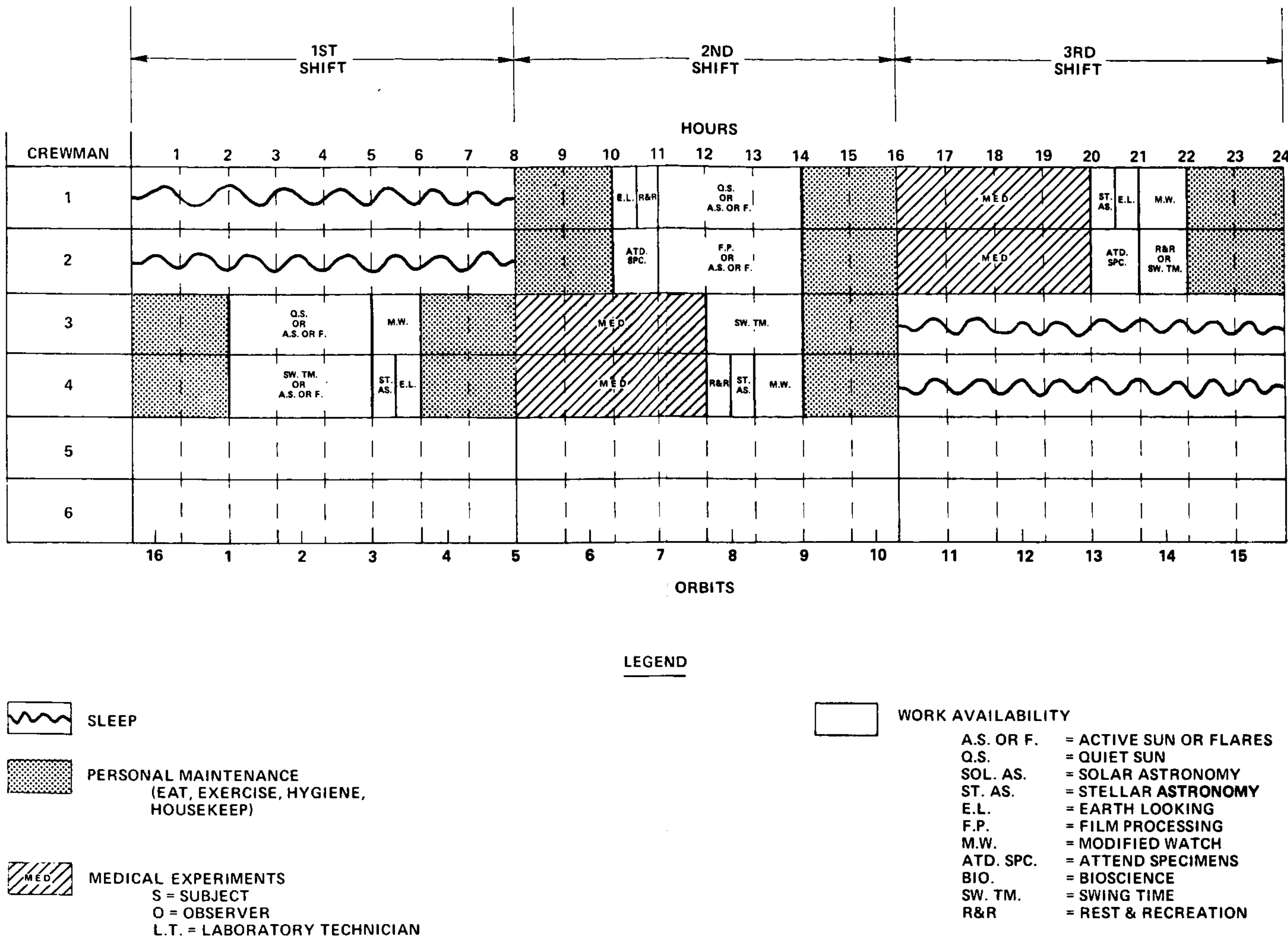


FIG. 11

DATA SUMMARY FOR FIGURE 11 (HOURS PER ACTIVITY)
4-MAN CREW (4 HR. MED. PROG.)
(2nd OPTION)

CREWMAN	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	MIN. DAY (TOTAL)	BUSY DAY (TOTAL)	R&R
1	1	4	3		½	1	-	-		-	9½	9½	½
2	-	4	-		-	-	3	2		-(2)	9	9	1(2)
3	1	4	3		-	-	-	-		2	8	10	-
4	1	4	-		1	½	-	-		3(2)	6½	9½	½
TOTAL	3	16	6		1½	1½	3(1)	2		5	33	38	2
										MED.	-16	-16	
								SA&T (+D.A.)			17(3)	22	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) May be excessive since less SOL. AS. is performed than with a 6-man crew.

2) Active sun wipes out C.M. #4's SW. TM., but C.M. #2's R&R now becomes SW. TM. This leaves 3 hrs. SW. TM. to pick up F.P. if necessary. Prefer to have F.P. require only 2 hrs., to leave 1 hr. for contingencies, such as repair. This avoids disruption of ongoing activities.

3) Note that Minimum Day is only 3 hrs. less than for 6-man crew, the Busy Day is 9 hrs. less.

On Schedule, note shift of orbit points with respect to time base (in practice it would be other way around) in order to begin solar observations at appropriate times.

Five-Man Crew (No Separate Schedule)

We're now closely approaching the six-man crew situation, which has already been analyzed at some length. Reference 2, showed that for the six-man case the best work program would be one in which only five men on the average would be assigned to connected type activities, and one man would usually be available for short duration tasks or contingency support. This would appear to indicate that without a sixth man you could still handle the minimum, routing workload of the six-man station. This is true, but with the fifth man carrying routine medical requirements, you couldn't conveniently do Active Sun or Flare type studies except on one of the three shifts. Also, you'd cut into the available time for Busy Day and contingency activities.

With five men you might want four of the men on the same schedule as for the four-man, second option (Fig. 11), with the fifth man operating free-floater style, except for a fixed sleep period, by himself, on the second shift. This way, with his regular medical requirements deleted for the one week stint (to be rotated among the crew), he would provide increased support and flexibility during the first and third shifts, when two men are sleeping.

Seven-Man (and up) Crew (No Separate Schedule)

As the crew grows to beyond six men in size, one of the first things we should attempt is to increase manpower availability and program flexibility where these factors suffer most, e.g., the three two-hour periods when the whole six-man crew is in Personal Maintenance. A seventh man could be made available during two of those three periods (he'd be asleep during one). The rest of the crew, when the seventh man was awake, could be on the Busy Day schedule without fear of interruption for most contingency tasks. The seventh man's role would be to perform those tasks or, in quiet times, to perform swing-time SA&T tasks. Again, being odd man out, his medical role should be minimized so as not to require support from the other crewmen, and the job could be rotated on a weekly basis.

Instead of employing the seventh man as above, primarily on a backup basis, with him and with larger crews you could begin to increase the technical activities in other fields. For example, you could bring bioscience or space physics into the program on a more frequent basis.

Also, as crews get larger the whole character of the onboard experiment program could begin to change. The emphasis on automation of experiments might be lessened, and more leeway built into the experiment program for manned participation through onboard modification of test setups and procedures.

C. 2.5-3.3 Hour Medical

The pros and cons of a reduced medical program were briefly presented in the text, Section III, Part A. By way of example we will now show the effects of implementing a schedule based on such lower levels of medical experimentation with a six-man and then a three-man crew.

Six-Man Crew (Figure 12)

In its simplest terms, as the schedules and data summaries of Figures 3 and 12 show, reduction of medical time from 4.5 down to an average of 2.9 hours per man for a crew of six results in having about nine more hours per day available for the support of other SA&T activities. Another result of significance is the removal of pressure that Hectic Day activities can bring to bear on the scheduling of the more routine activities. There are enough uncommitted periods in the day, now, so that the need for Active Sun or Flare coverage or the performance of a repair during a normally scheduled activity poses little problem in rescheduling that activity; e.g., each Modified Watch period is now immediately followed by a swing-time period to which it could readily be postponed if desired.

Also, on the reduced medical program crew interest should be easier to maintain, due to the greater variety of tasks they may now perform. As with crew sizes larger than six on the four-hour medical program, some of these extra tasks could, if desired, now be scheduled on a regular basis, thus increasing the planned output of the mission.

It is desirable, of course, to have as many uninterrupted two- to three-hour periods as possible available for swing-time tasks. Scheduling stellar astronomy and earth looking at uniform intervals, as done in the Reference Mission, would inhibit this. Instead they are plugged into other gaps, too short for use as swing time, with some not very significant loss in regularity.

If it is desired to use available specialized skills or to develop competence in certain areas, repetitive assignment of the same type tasks to the same man should be made, as is shown for crewmen number 4 and number 6 with Stellar Astronomy and Earth Looking respectively. For Attend Specimen, which is done only twice a day, you may want at least two people on different shifts qualified. You would not give the tasks to the same man, then.

FIGURE 12 - CREW INFLIGHT SCHEDULE - 6 MEN
(2.5-3.3 HR MED PROGRAM)

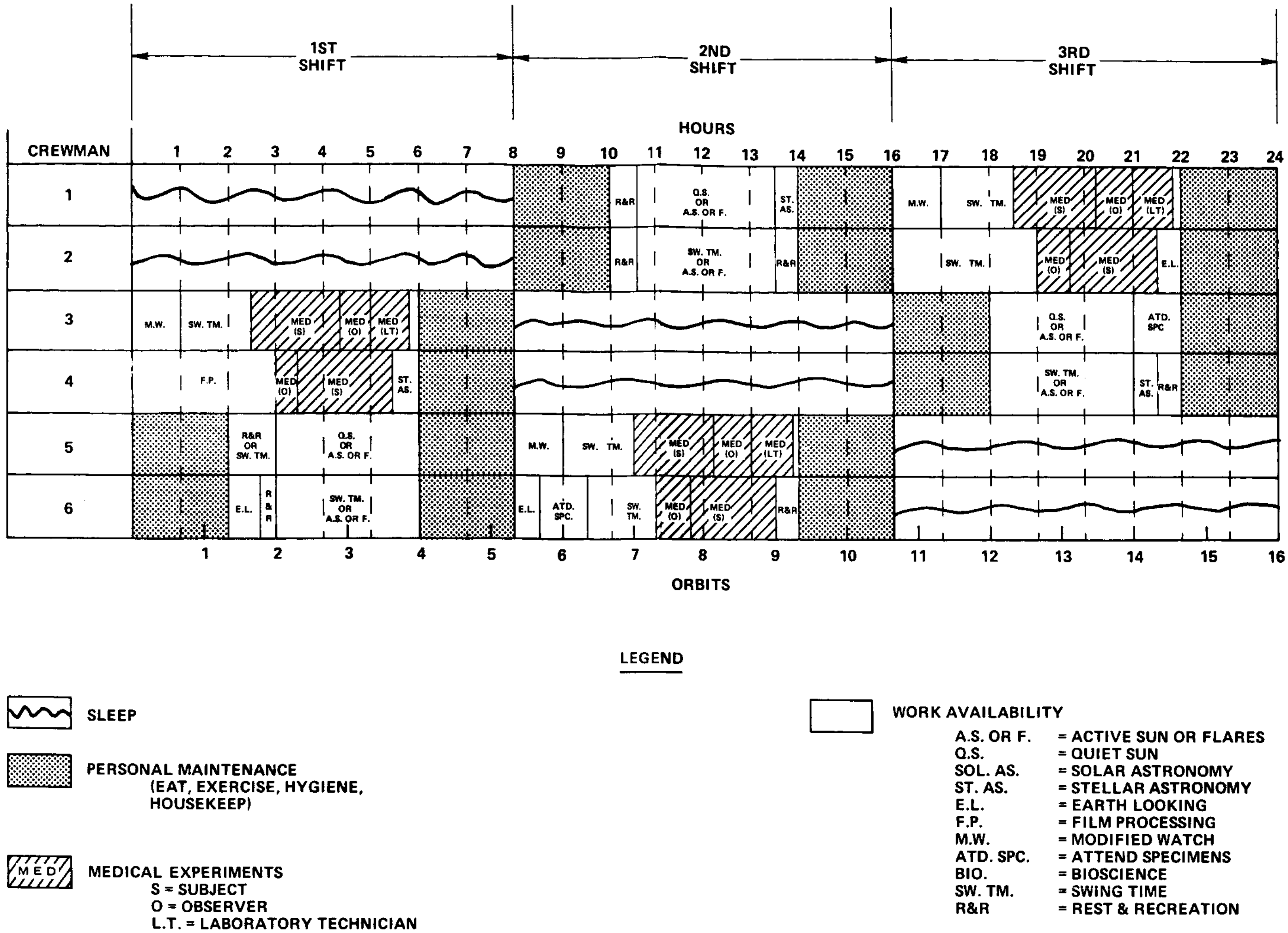


FIG. 12

DATA SUMMARY FOR FIGURE 12 (HOURS PER ACTIVITY)
6-MAN CREW (2.5-3.3 HR. MED. PROG.)

CREWMAN	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	TOTAL MIN. DAY	TOTAL BUSY DAY	R&R
1	1	3½	3		½	-	-	-		1½	8	9½	½
2	-	2½	-		-	½	-	-		6	3	9	1
3	1	3½	3		-	-	-	1		1½	8½	10	-
4	-	2½	-		1	-	3	-		3	6½	9½	½
5	1	3½	3		-	-	-	-		1½	7½	9	1
6	-	2½	-		-	1	-	1		4½	4½	9	1
TOTAL	3	18	9		1½	1½	3 (1)	2		18	38	56	4
										MED.	-18	-18	
										SA&T (+D.A.)	20	38	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) The F.P. task can be rotated between C.M. #4, as shown, and C.M. #2, who has a 3 hr. SW. TM. period available. During Q.S. others could do it, too.

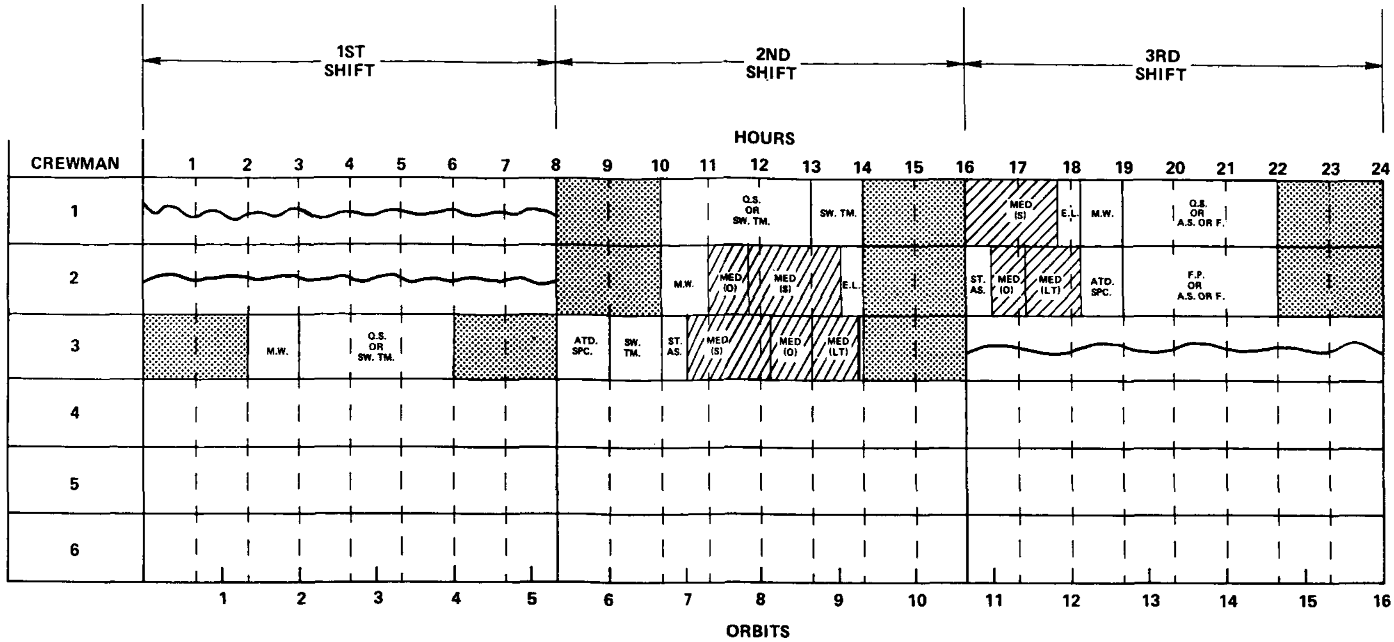
<u>Three-Man Crew</u> (Figure 13)

The three-man crew on the indicated, reduced medical program is only one hour short of being able to properly handle the complete minimum SA&T load of the six-man Reference Mission. It would, however, only be able to handle the contingency Active Sun observations on one of the three shifts, due to lack of a backup man, and other contingency events would also pose a problem. If AS or F design or operation were modified for one-man operation, then this crew could practically meet all the technical objectives of the Reference Mission.

Though the schedule is tight, with each man having a variety of jobs, there would still be a total of two hours of swing time during the day. While these considerations are for a ten hour per man work day, increasing the work day would, as a practical matter, simply introduce more flexibility into the scheduling rather than substantially increase the output.

A cursory examination of Figure 13 prompts the author to conjecture that a three-shift sleep schedule might be more advantageous here. Besides obviating the two versus one potential psychological problem, it appears that it might present two shifts during which active sun observations could be supported. If cost or other considerations were to favor small crews and if the shorter duration medical testing were acceptable, such a three-man scheme would appear very attractive. (Equivalent to saying that AAP-3a and 4 could be readily combined if ATM and medical requirements were sufficiently eased.)

FIGURE 13 - CREW INFLIGHT SCHEDULE - 3 MEN (2ND OPTION)
(2.5-3.3 HR MED PROGRAM)



LEGEND

SLEEP

PERSONAL MAINTENANCE (EAT, EXERCISE, HYGIENE, HOUSEKEEP)

MED — MEDICAL EXPERIMENTS
- S = SUBJECT
- O = OBSERVER
- L.T. = LABORATORY TECHNICIAN

WORK AVAILABILITY

- A.S. OR F. = ACTIVE SUN OR FLARES
- Q.S. = QUIET SUN
- SOL. AS. = SOLAR ASTRONOMY
- ST. AS. = STELLAR ASTRONOMY
- E.L. = EARTH LOOKING
- F.P. = FILM PROCESSING
- M.W. = MODIFIED WATCH
- ATD. SPC. = ATTEND SPECIMENS
- BIO. = BIOSCIENCE
- SW. TM. = SWING TIME
- R&R = REST & RECREATION

FIG. 13

DATA SUMMARY FOR FIGURE 13 (HOURS PER ACTIVITY)
3-MAN CREW (2.5-3.3 HR. MED. PROG.)
(2nd OPTION)

CREWMAN	M.W.	MED.	Q.S.	(SOL. AS.)	ST. AS.	E.L.	F.P.	ATD. SPC.	(BIO.)	SW. TM.	TOTAL MIN. DAY	TOTAL BUSY DAY	R&R
1	1 (1)	1¾ (2)	6		-	½	-	-		1	9	10	-
2	1	4	-		½	½	3	1		-	10	10	-
3	1	3¼	3		½	-	-	1		1	9	10	-
TOTAL	3	9	9 (3)		1	1	3 (4)	2		2	28	30	-
										MED.	- 9	- 9	
										SA&T (+D.A.)	19	21	

COMMENTS ON SCHEDULE AND DATA SUMMARY

1) Actually, this is hedged by 5 minutes, to give E.L. 20 minutes.

2) Excellent example of preconceived notion(of 2.5 hr. min. med. requirement) being in error. All med. req'ts are met by indicated scheduling, which was optimized for other activities.

3) Could be as low as 6 hrs., if Q.S. is not allowed to begin at different parts of an orbit.

4) May be excessive due to reduced solar observations (max. of 3 hrs. A.S. or F.) compared with 6-man crew (up to 9 or more hrs. A.S. or F.).

Scheduling more activities (than in 4 hr. MED. case) restricts when each can be performed; e.g., ST. AS. and E.L. can no longer be assigned to just 1 or even 2 men (due to ephemeris conflicts).